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FEBRUARY 1931

PENNSYLVANIAN OVERLAP IN UNITED STATES[1]

A. I. LEVORSEN[2]
Tulsa, Oklahoma

ABSTRACT

This is a regional study of one of the great unconformities of the geologic record. Cross sections show the wedging-out of the formations above and below the basal Pennsylvanian unconformity as the center of the United States is approached. This is further shown by isopachous maps of the deposits of Pottsville age and of the rocks of Upper Mississippian age. An areal map of the pre-Pennsylvanian rocks shows that as the Pennsylvanian seas covered the country, the pre-Pennsylvanian rocks had the general form of a great arch extending from New Mexico northeast into Minnesota and the pre-Cambrian shield of Canada. Along this axis, pre-Cambrian rocks were exposed and, farther from the axis, both east and west, progressively younger systems were exposed to the advancing Pennsylvanian seas, so that, at the margins of the country, rocks of Upper Mississippian age were in contact with rocks of lower Pottsville age.

The principal results of the study are the evidence about the presence and nature of this continental arch in the west-central states; the thinning of the rocks of Pottsville age as the axis is approached, due chiefly to progressive overlap in this direction; the thinning of the Upper Mississippian rocks in the same direction, due chiefly to progressively deeper erosion as the axis is approached; the character and position of the folds present in pre-Pennsylvanian time; the probable connection of the Pottsville from Pennsylvania to West Texas; and the source of a substantial amount of the Pottsville sediments through the erosion of the pre-Pennsylvanian rocks from the crest of this continental arch.

INTRODUCTION

One of the great unconformities and overlaps of the geologic record is at the base of the Pennsylvanian system. A regional study of some of the characteristics of this unconformity and overlap as it is found in

[1] Read before the Association at the New Orleans meeting, March 22, 1930. Manuscript received, December 12, 1930.

[2] 1740 South St. Louis Street. Formerly chief geologist, Independent Oil and Gas Company.

the United States has been made by the writer, and the resulting maps, cross sections, and conclusions are presented in this paper. Many of the other systemic boundaries are adapted to the same treatment, but the basal boundary of the Pennsylvanian system was studied first because of its widespread occurrence in the United States and because of its many published descriptions.

More than one thousand references to the geologic literature were used to obtain the data on which the maps, cross sections, and results are based. Discussions with many geologists working on the stratigraphic problems of the Mid-Continent region furnished an important part of the data used in that area and this assistance is here gratefully acknowledged. In addition, much information pertinent to the problem came to the writer through his practice of commercial geology in the Mid-Continent states. As the maps and sections are the chief result of the study, and as a listing of all of the references used would make an extremely cumbersome paper, it was decided to eliminate nearly all of the references, with the general acknowledgment that all of the material comes from outside sources and that responsible references are available for the facts described.

Oil wells are being drilled and other underground explorations are continually being made in many states, and, as the rock cuttings are examined and correlated, a large amount of additional information becomes available from year to year. Much detailed stratigraphic work remains to be done on the Paleozoic systems, particularly in the western states, where the Carboniferous in many places is undifferentiated. Therefore, the maps and sections—particularly the pre-Pennsylvanian areal map (Plate 1)—are subject to revision and changes as our knowledge of the stratigraphy increases.

OUTLINE

The text which follows is chiefly a brief description of the maps and stratigraphic sections, which contain all of the information available to the writer and which are arranged in the following sequence.

1. A key map showing the areal divisions and the locations and numbers of the stratigraphic cross sections.

2. Correlation tables showing the correlations used in preparing the maps and sections. These show the inter-state and the inter-division correlations.

3. Stratigraphic cross sections showing the relations of the Pennsylvanian sediments to the pre-Pennsylvanian sediments in different

areas. The locations and numbers of these sections are shown on the key map (Fig. 1).

4. An isopachous map showing the locations and thickness of the rocks of Pottsville age in the United States.

5. An isopachous map showing the locations and thickness of the rocks of Upper Mississippian age in the United States.

6. A map showing the areal distribution of the rocks underlying the Pennsylvanian sediments in the United States. This map represents the areal geology of the United States as the Pennsylvanian seas advanced across the country.

7. Several maps showing in detail the evidence on which certain areas are mapped as described under the preceding paragraph.

8. A short discussion of some of the writer's interpretations of the facts as presented in the maps and cross sections.

DESCRIPTION OF MAPS AND SECTIONS

Figure 1 is a key map showing the present areal distribution of the rocks of post-Permian age; the rocks of Permian-Pennsylvanian age; and the rocks of pre-Pennsylvanian age. It also shows the districts into which the correlation tables (Figs. 2, 7, 10, and 14) are separated: (1) Appalachian states, (2) Mississippi Valley states, (3) northern states, (4) Mid-Continent states, and (5) western states. The locations of these stratigraphic sections are shown as *AB*, *CD*, *EF*, et cetera.

The dotted area in Figure 1 indicates the location of post-Permian rocks at the surface, or that part of the United States in which the Permian and older rocks are overlapped and covered by the younger formations. Within this area, which almost encloses the central and eastern states, information about the basal Pennsylvanian unconformity is limited to the bore holes and other excavations which expose the contact. Although considerable information is available in some of the oil-producing states within this area, there is no definite information about the base of the Pennsylvanian in many states; consequently, the maps become less accurate as these unknown areas are approached.

The area shaded in Figure 1 is the area in which rocks of Permian and Pennsylvanian age are found at the surface. Much of the control of the stratigraphy, character, and location of the base of the Pennsylvanian is within these shaded areas. The contact of the shaded areas with the blank areas furnishes numerous exposures, nearly all of which have been described in the geologic literature. As the surface formations are known in the other parts of the shaded areas, correlations of the

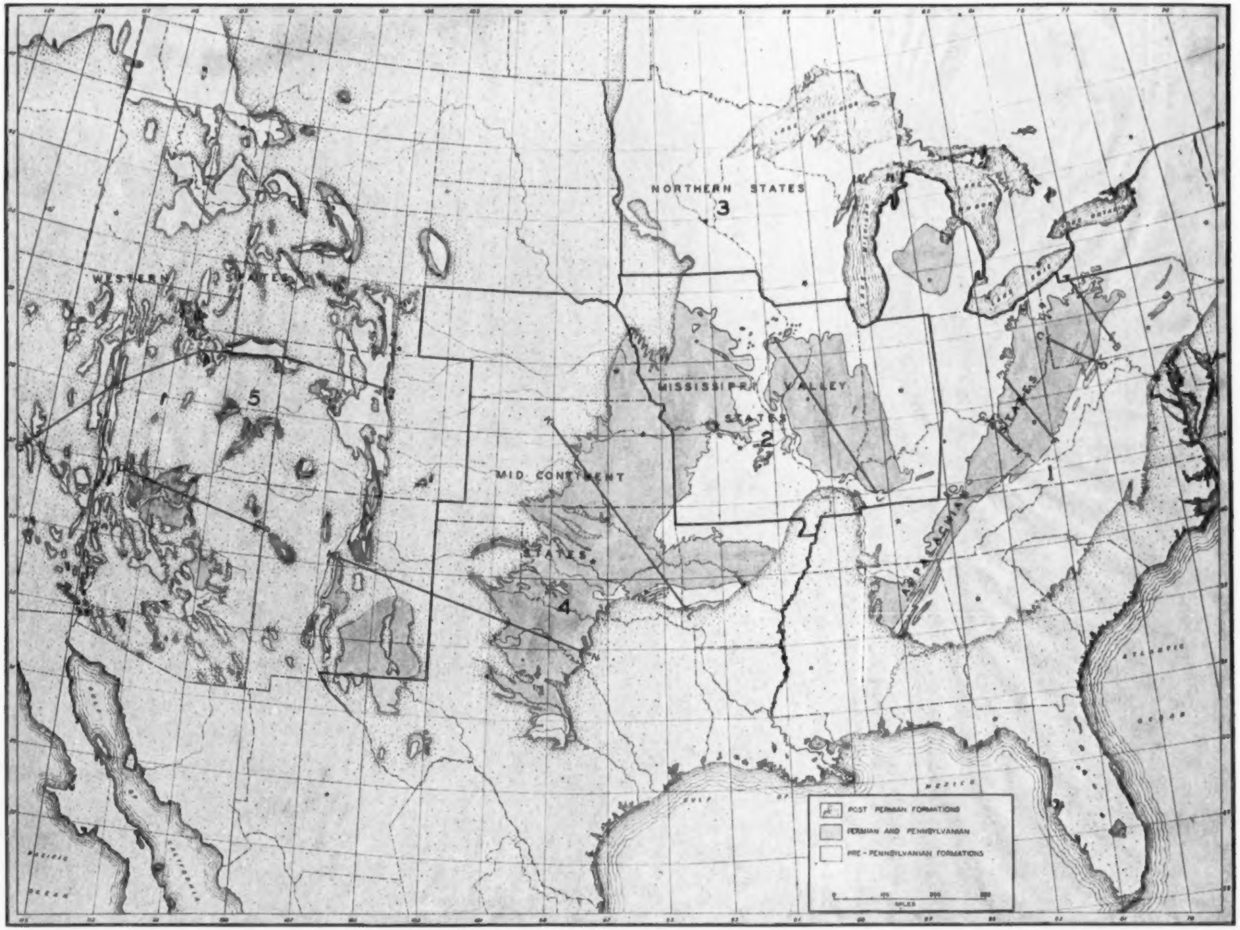


FIG. 1.—Key map of the United States, showing the present areal distribution of the post-Permian, Permian and Pennsylvanian, and pre-Pennsylvanian rocks; the locations of the districts considered in this paper; and the locations of the stratigraphic sections.

drill-hole cuttings and logs are more accurate than in the dotted areas, and in general there is ample control to make possible the preparation of the isopachous map and stratigraphic sections.

The blank area of Figure 1 shows the distribution of the rocks of pre-Pennsylvanian age. Only where the Upper Mississippian rocks are exposed is it possible to know the age of the rocks present at the beginning of Pennsylvanian deposition. There is some evidence, however, which gives a reasonable idea of the pre-Pennsylvanian areal geology in the northern states division (3) and which is discussed later. In general, the area shown in blank is the area of least present and future control of the character of the rocks and stratigraphy adjacent to the base of the Pennsylvanian, as the formations involved have been removed by erosion, chiefly in post-Pennsylvanian time.

APPALACHIAN STATES AREA[1]

Pennsylvanian sediments are found in a belt extending southwest from Pennsylvania and eastern Ohio to northern Alabama. They dip southeast away from the Cincinnati and Nashville domes along the west side of the belt and are highly folded and faulted as a part of the Appalachian Mountain folding along the east side of the belt. A complete section of the Pennsylvanian rocks is found only in the northern part of this area, as erosion has removed everything down to and including the upper part of the Pottsville in the southern part of the area. The Pottsville is everywhere the basal Pennsylvanian formation in the eastern states. It thins toward the northwest by the progressive overlap of the older members by younger members in this direction. The Pottsville reached a thickness of more than 6,500 feet in western Virginia and more than 7,400 feet in northern Alabama. The distribution and thickness of the Pottsville is shown in Figure 17.

The Pottsville rocks rest unconformably on rocks of Upper Mississippian age except in a narrow zone on the east side of the Cincinnati arch, where they overlap the Upper Mississippian and rest on Middle and Lower Mississippian rocks, and in northwestern Pennsylvania, where they overlap the Mississippian formations and rest on rocks of Devonian age. The Upper Mississippian thins toward the northwest, due chiefly to pre-Pennsylvanian erosion of the upper members in this direction. The maximum thickness of the Upper Mississippian is in the easternmost exposures in western Virginia, where it is more than

[1]Area 1 in Figure 1.

FIG. 1.—Key map of the United States, showing the present areal distribution of the post-Permian, Permian and Pennsylvanian, and pre-Pennsylvanian rocks; the locations of the districts considered in this paper; and the locations of the stratigraphic sections.

5,000 feet. The distribution and thickness of the rocks of Upper Mississippian age are shown in Figure 18.

Figure 2 shows the critical geologic sections of the eastern states and the correlations used in this paper. Only the formations adjacent to the basal Pennsylvanian unconformity are shown. The stratigraphic sections (Figs. 3, 4, 5, and 6) show the generalized relations of the formations above and below the base of the Pennsylvanian system. The top of the Pottsville is used as a reference plane in each of the cross sections.

CENTRAL STATES AREA[1]

Pennsylvanian sediments occupy large areas in the central part of the United States bordering Mississippi and lower Ohio rivers. Southeast of a line extending from northeast Missouri to northern Michigan, the Pottsville formation is the basal Pennsylvanian formation. Northwest of this line, the Middle Pennsylvanian rocks overlap the Lower Pennsylvanian rocks and form the basal Pennsylvanian formation. The Pottsville sediments thin out toward the north and west, chiefly because of overlap by the younger members in this direction.

The Pottsville rests unconformably on rocks of Upper Mississippian age south of a line drawn between St. Louis, Missouri, and Terre Haute, Indiana. The Upper Mississippian, consisting of the Chester series above and the Ste. Genevieve limestone below, thins out toward the north, chiefly because of progressively deeper pre-Pennsylvanian erosion in this direction. The type localities of the Chester series and of the Ste. Genevieve limestone are in southern Illinois, where they have been carefully described by Stuart Weller of the Illinois Geological Survey. The distribution and thickness of the Pottsville rocks are shown in Figure 17, and of Upper Mississippian rocks in Figure 18.

The contact between the Pennsylvanian and the underlying older formations is generally described as an erosional, and in places an angular, unconformity. North and west of the Upper Mississippian area the Pennsylvanian rests on progressively older pre-Pennsylvanian formations, the oldest of which are Ordovician in age in northern Illinois and in eastern Iowa. The hiatus represented by the unconformity increases toward the north and west.

Figure 7 shows the critical geologic sections of the central states and the correlations used in this paper. Only the formations adjacent to the base of the Pennsylvanian system are shown. The stratigraphic

[1]Area 2 in Figure 1.

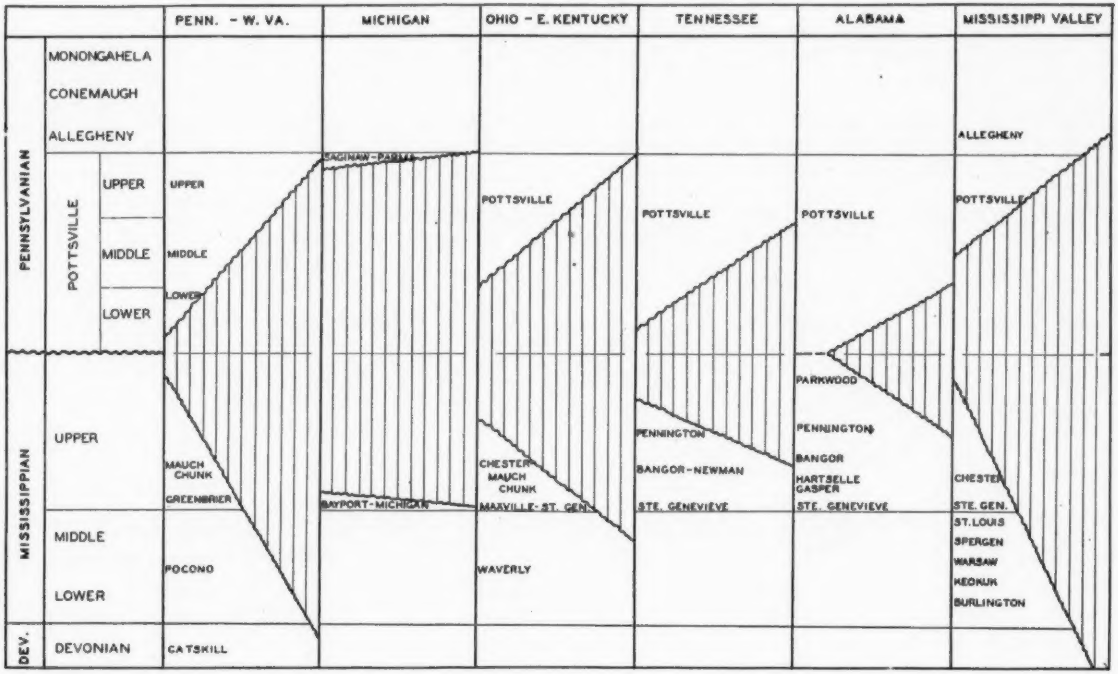


Fig. 2.—Correlation chart of formations occurring adjacent to the basal Pennsylvanian unconformity in the Appalachian states as used in this paper. (Area 1 in Figure 1.)

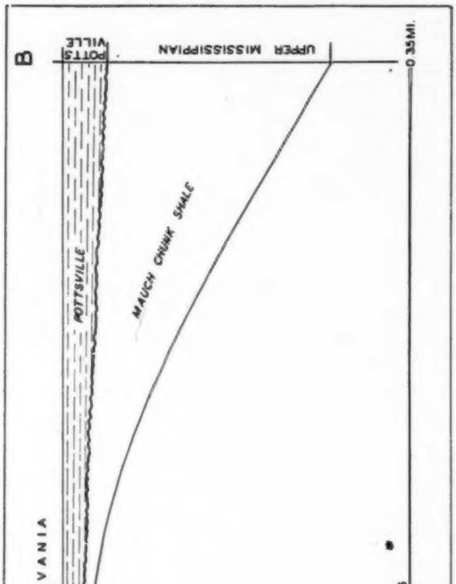


FIG. 3.—Stratigraphic cross section across Pennsylvania, showing overlap of pre-Pennsylvanian formations by Pottsville formation. Also shows northwestward thinning of Pottsville and Upper Mississippian formations. Datum plane is top of Pottsville. Location of section shown by line *AB* in Figure 1.

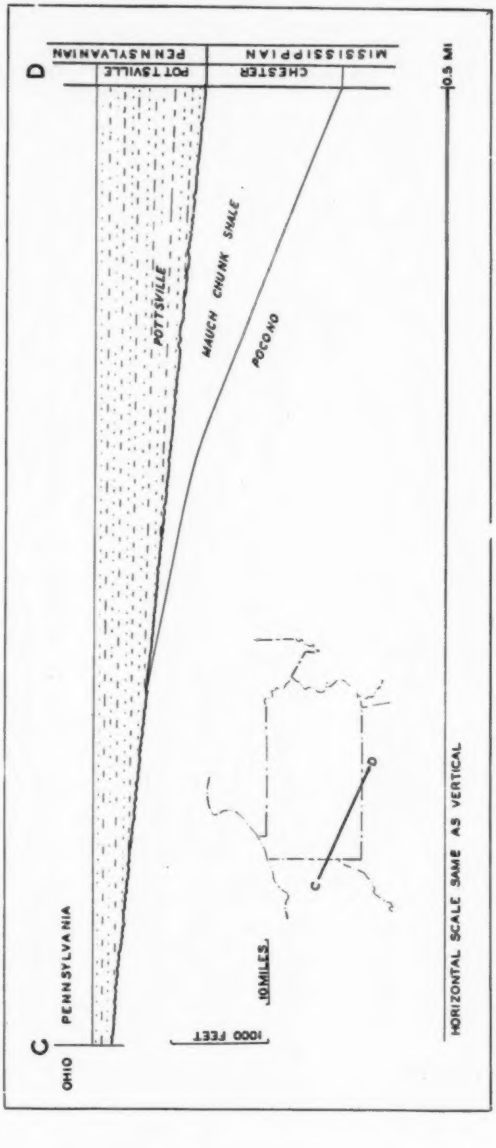


FIG. 4.—Stratigraphic section across Pennsylvania, showing overlap of pre-Pennsylvanian formations by Pottsville formation. Also shows westward thinning of Pottsville and Upper Mississippian formations. Datum plane is top of Pottsville. Location of section shown by line *CD* in Figure 1.

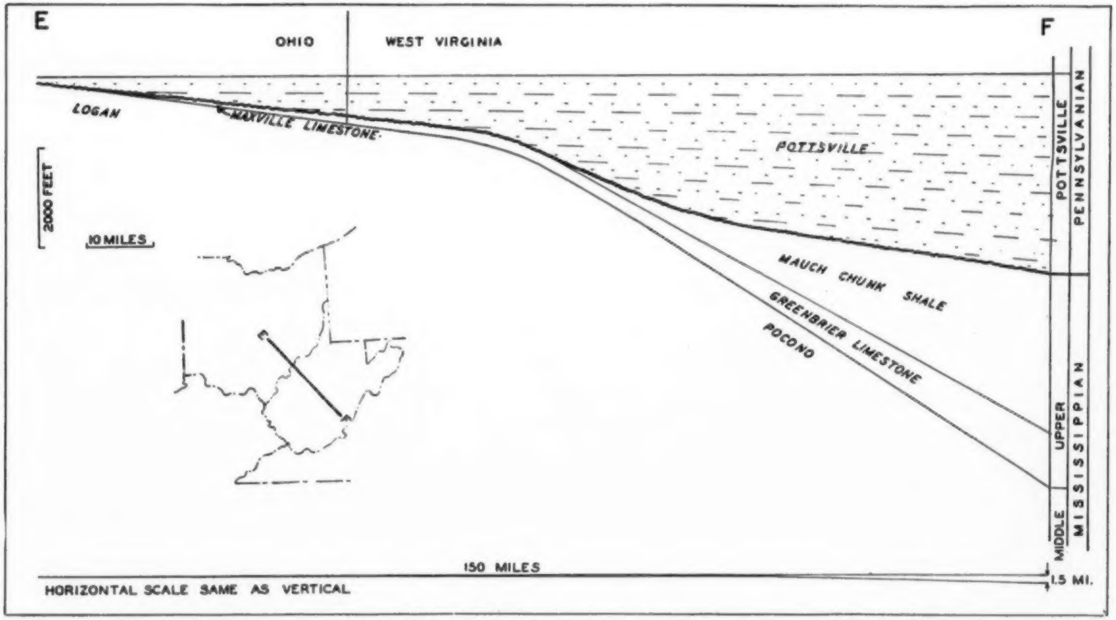


FIG. 5.—Stratigraphic section across West Virginia into Ohio, showing overlap of pre-Pennsylvanian rocks by Pottsville formation. Also shows northwestward thinning of Pottsville and Upper Mississippian formations. Datum plane is top of Pottsville. Location of section shown by line *EF* in Figure 1.

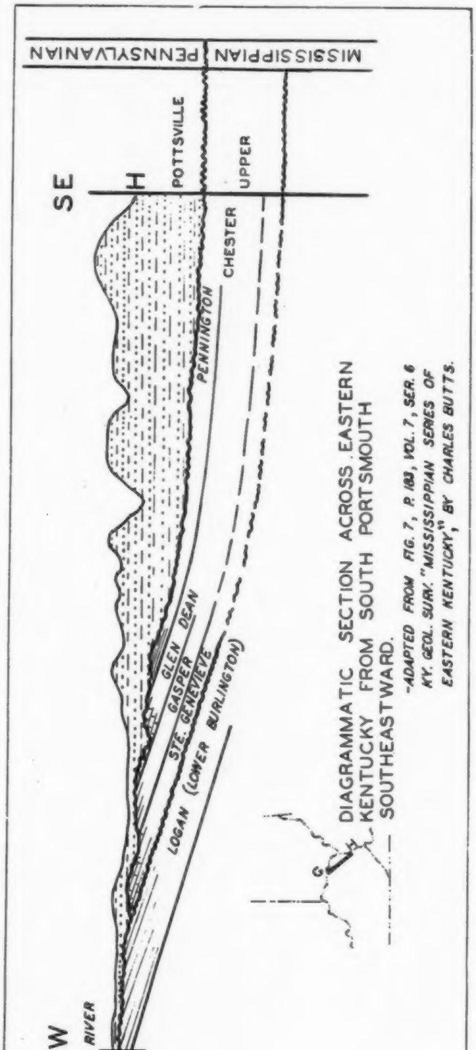


Fig. 6.—Stratigraphic section across eastern Kentucky, showing overlap of pre-Pennsylvanian rocks by Pottsville formation. Also shows northwestward thinning of Pottsville and Upper Mississippian formations. Location of section shown by line *GH* in Figure 1.

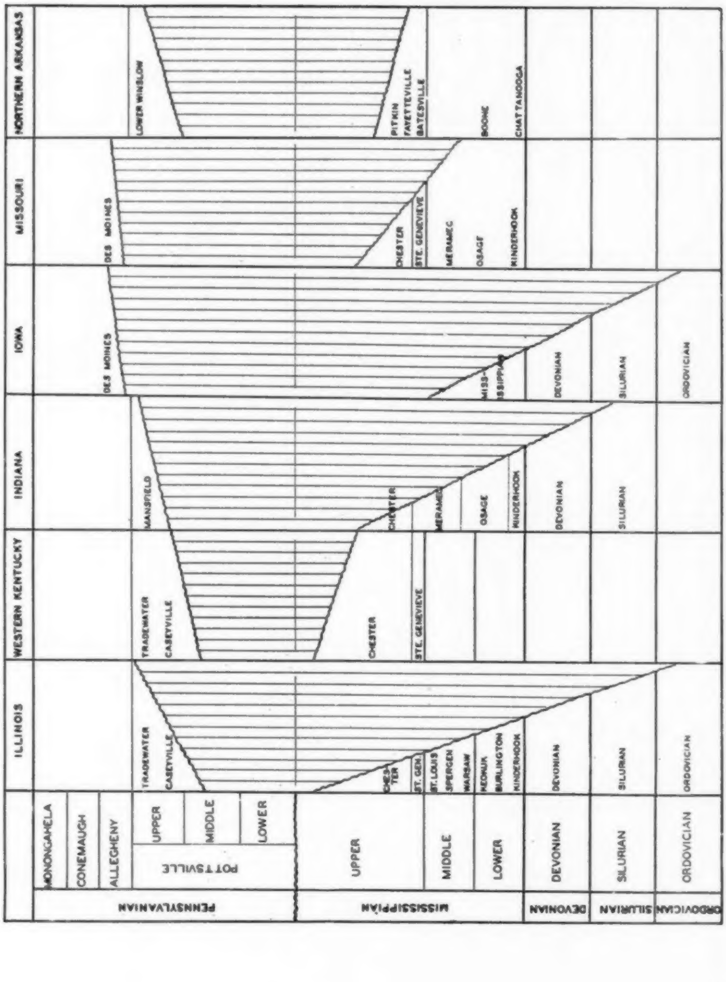


FIG. 7.—Correlation chart of formations occurring adjacent to basal Pennsylvanian unconformity in Mississippi Valley states as used in this paper. (Area 2 in Figure 1.)

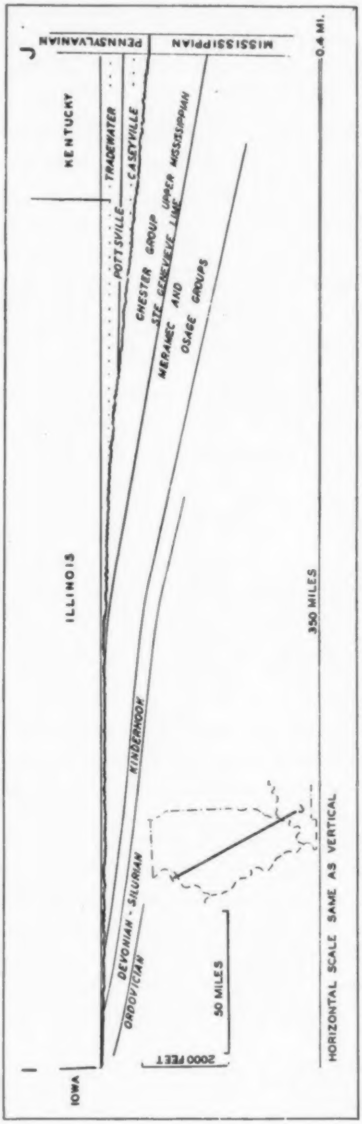


FIG. 8.—Generalized cross section from western Kentucky to northern Illinois, referred to top of Pottsville as datum plane. Location of section shown by line *IJ* in Figure 1.

section (Fig. 8) shows the relation of the formations above and below the base of the Pennsylvanian along a line extending across Illinois and into western Kentucky. The top of the Pottsville formation is the datum plane.

NORTHERN UNITED STATES FROM MINNESOTA TO NEW YORK[1]

The northern part of the United States extending from Minnesota to New York is north of the northernmost limits of the great mass of Pennsylvanian sediments as found to-day. With the exception of the large outlier of Pennsylvanian rocks in the basin of southern Michigan, there is little or no direct evidence in this region of the areal geology at the time the Pennsylvanian seas advanced over it. There is, however, some indirect evidence that the areal geology at that time was in general very similar to that found to-day. It is on the basis of this indirect evidence that the areal geology of that time is extended into this northern area of no direct control in the pre-Pennsylvanian areal map (Pl. 1). The nature of this indirect evidence is shown in the following paragraphs.

Figure 9 is the detail of an area in southeastern Iowa taken from the state geological map.[2] It shows several small outliers or remnants of Pennsylvanian sediments northeast of the main mass of the Pennsylvanian. They rest on each of the formations ranging from the St. Louis limestone (Middle Mississippian) to the Niagara limestone (Silurian) without change in the direction of the pre-Pennsylvanian formation contacts. Two small outliers in Louisa County are particularly significant. Although they are only two miles apart, one rests on St. Louis limestone and the other on rocks of Osage age and there is no deviation from the pre-Pennsylvanian direction of the contact. In other words, there has been no important change in the line of contact between these pre-Pennsylvanian formations since the time the Pennsylvanian sediments were deposited.

This same condition is found in northwestern Illinois,[3] where several Pennsylvanian outliers rest on rocks of Devonian age, and in the northern part of the Ozark uplift, where Pennsylvanian outliers rest on rocks of Cambro-Ordovician age only a short distance from the contact of the Pennsylvanian with Mississippian limestones.

The geologic maps of Illinois and Iowa, particularly, also show that the contacts between different pre-Pennsylvanian formations continue

[1]Area 3 in Figure 1.

[2]T. E. Savage, "Geological Map of Iowa," *Iowa Geol. Survey* (1901).

[3]"Geologic Map of Illinois," *Illinois Geol. Survey* (1917).

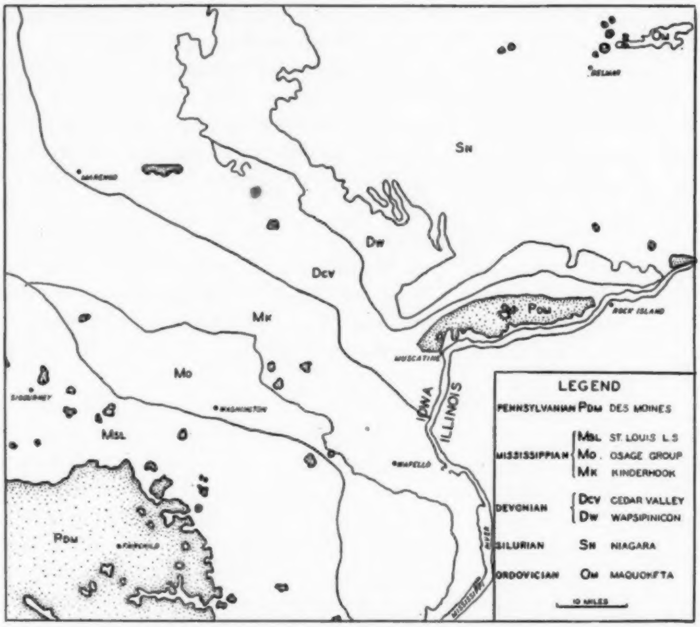


FIG. 9.—Areal geology of an area in southeastern Iowa, taken from state geologic map by Savage. Shows detail of overlap of Pennsylvanian formations on eroded edges of pre-Pennsylvanian formations. Dotted areas are Pennsylvanian.

without appreciable change in direction as they emerge from the large areas of Pennsylvanian cover. Thus the present location of the contacts between the Mississippian, Devonian, Silurian, and Ordovician in northern Illinois are extensions of the contacts as found beneath the Pennsylvanian cover on the south. This condition is true also in northwestern Pennsylvania, Ohio, Indiana, and southern Michigan.

The writer believes, therefore, that there is justification for considering the pre-Pennsylvanian areal geology of this northern area of no present direct control and for considering the post-Paleozoic deformation relatively small and essentially as now found.

MID-CONTINENT STATES AREA[1]

Pennsylvanian sediments occupy a large area in the Mid-Continent states extending from Iowa and Nebraska to western Texas. They are

[1]Area 4 in Figure 1.

covered at the southeast and west by rocks of Cretaceous and Permian age. Rocks of Pottsville (Lower Pennsylvanian) age are found at the base of the Pennsylvanian in the southeastern part of the area in western Arkansas, eastern Oklahoma, north-central and western Texas, and possibly in northeastern Kansas and northwestern Missouri. The Pottsville rocks thin out toward the west and northwest, chiefly as a result of the overlap of the older members by the younger members in this direction.

Where the Pottsville is present, it generally rests on rocks of Upper Mississippian age. The Upper Mississippian formations thin out toward the west and northwest chiefly because of progressively deeper pre-Pennsylvanian erosion in this direction. The subdivisions of both the Pottsville and the Upper Mississippian rocks are shown in the correlation chart (Fig. 10).

The distribution and thickness of the rocks of Pottsville age are shown in Figure 17, and the rocks of Upper Mississippian age in Figure 18.

The contact between the Pennsylvanian rocks and the pre-Pennsylvanian rocks is nearly everywhere an erosional, and in some places an angular, unconformity. Where the Morrow-Bend group is present it is overlain by another unconformity which may be the greater of the two. Much of the deformation which localized the pre-Pennsylvanian oil pools occurred during the time represented by these unconformities. Round, frosted sand grains such as occur in the Cambro-Ordovician sandstones are common in the Lower Pennsylvanian sands of this area. These sand grains are not commonly found in the Mississippian rocks except in the basal Sylamore or Misener sandstone; they indicate the erosion of Cambro-Ordovician sandstones in early Pennsylvanian time.

The younger pre-Pennsylvanian formations occur on the eastern side of the Mid-Continent area. Westward the Pennsylvanian system transgressively overlaps older pre-Pennsylvanian rocks. Thus, in eastern Oklahoma the Pottsville rests on Upper Mississippian rocks; in northern Oklahoma and central Kansas post-Pottsville Pennsylvanian rocks rest on Middle and Lower Mississippian limestones; and in western Kansas Middle and Upper Pennsylvanian rocks rest on Ordovician and older strata. An exception is the outlier of Upper Mississippian rocks recently found extending throughout a large area in northwestern Oklahoma and southwestern Kansas. This undoubtedly represents a synclinal area in pre-Pennsylvanian time in which the Upper Mississippian rocks were protected from the erosion which occurred prior to the deposition of the Pennsylvanian.

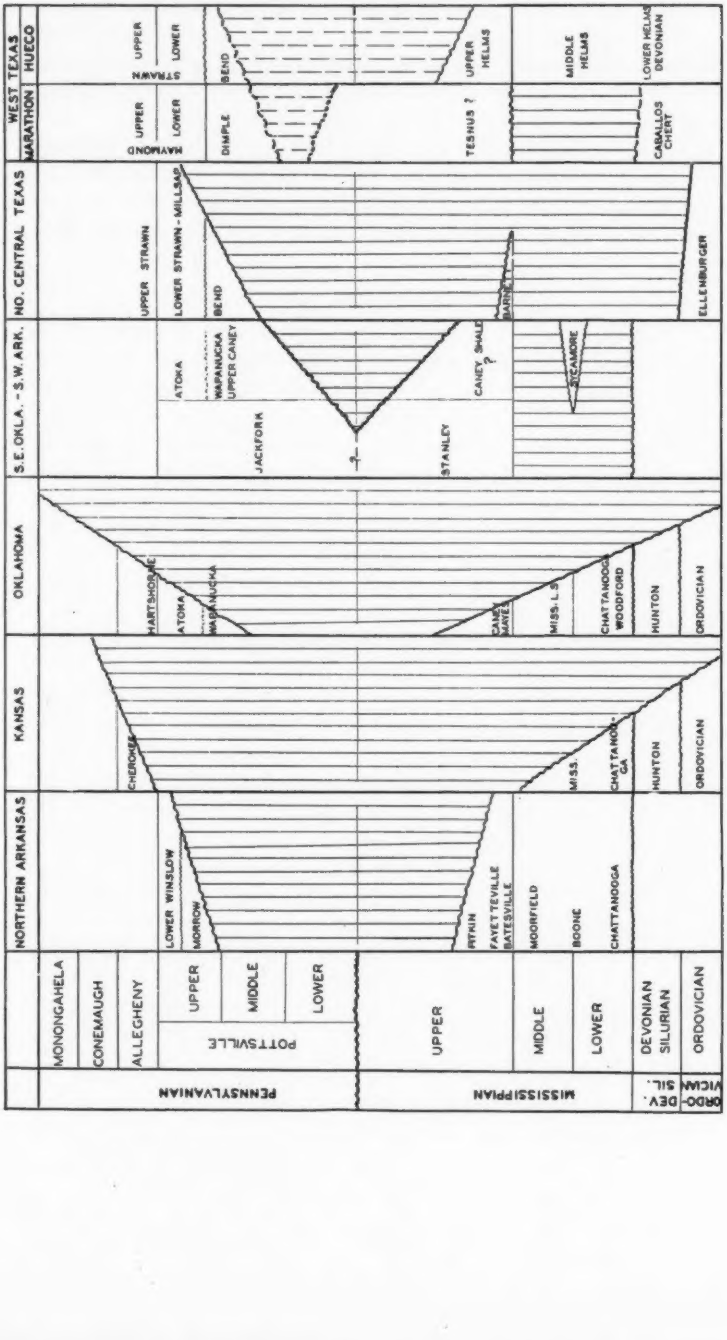


FIG. 10.—Correlation chart showing subdivision of Pottsville, Upper Mississippian, and formations adjacent to basal Pennsylvanian unconformity in Mid-Continent states as used in this paper. (Area 4 in Figure 1.)

Figures 11 and 12 show northwest-southeast stratigraphic sections across Kansas and Oklahoma and across northeastern New Mexico and northern Texas respectively. These sections show, in general, the nature of the overlap of the Pennsylvanian and the progressively deeper erosion of the pre-Pennsylvanian formations toward the northwest.

Figure 13 indicates in detail the formations underlying the Pennsylvanian in a small area in south-central Oklahoma. With the exception of the exposure in the Arbuckle Mountains, this map is based on information obtained from well records and cuttings in the Seminole-Oklahoma City district.

WESTERN STATES AREA[1]

There are relatively few large areas of continuous outcrop of the Pennsylvanian rocks in the western states. Our knowledge of the Pennsylvanian, therefore, and the age and character of the underlying rocks is based on widely separated, but in many places detailed, geologic sections. Earlier geologic reports on this region ordinarily grouped the different systems as "Carboniferous" or "undifferentiated Carboniferous," but later work has separated the different systems and some detailed correlations are made possible. Future work will undoubtedly add much detail to the present information.

Rocks of Pottsville age have been described in a few isolated localities in the western states, the location of which is shown in Figure 17. In general, the basal Pennsylvanian formations belong to the middle and upper part of the Pennsylvanian system.

Upper Mississippian rocks are found west of a line connecting southeast New Mexico, east-central Utah, and central Montana, as shown in Figure 18. They generally become thicker toward the west, and the Pennsylvanian rocks rest on older formations toward the east, suggesting, in part, progressively deeper erosion in this direction. Sufficient detailed stratigraphic work is not yet available to show the manner of the eastward thinning.

Eastward from the Upper Mississippian occurrences, the Pennsylvanian rocks rest progressively on Middle and Lower Mississippian, Devonian, Silurian, Ordovician, and pre-Cambrian rocks. The pre-Cambrian rocks generally underlie the Pennsylvanian at its easternmost exposure on the Rocky Mountain front south of southeastern Wyoming. There is a large area in the Great Plains region between the western

[1]Area 5 in Figure 1.

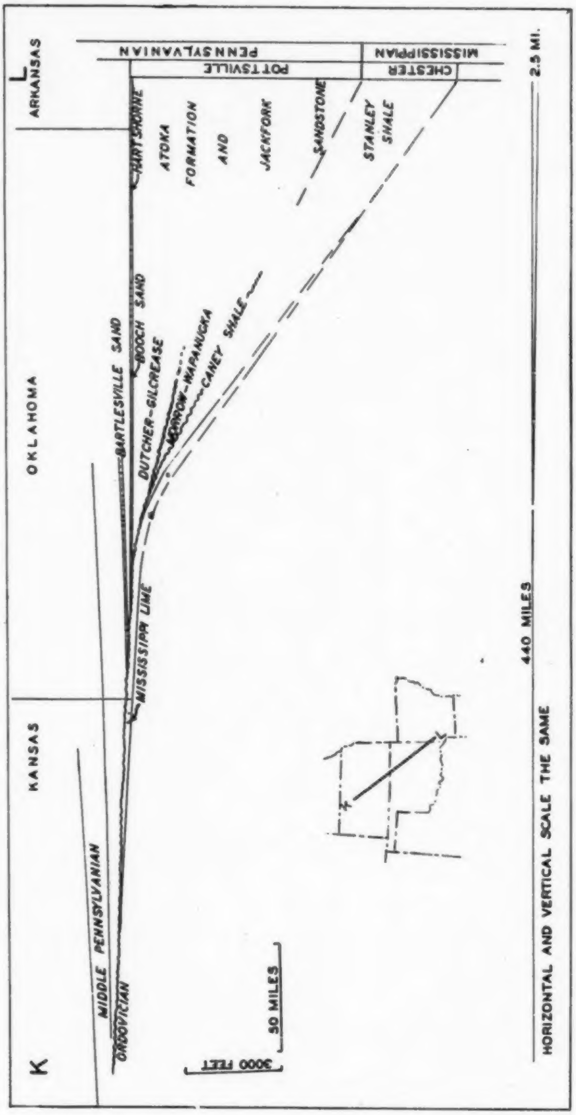


FIG. 11.—Northwest-southeast stratigraphic section across Kansas and Oklahoma. Location of section shown by line *KL* in Figure 1. Referred to top of Pottsville as datum.

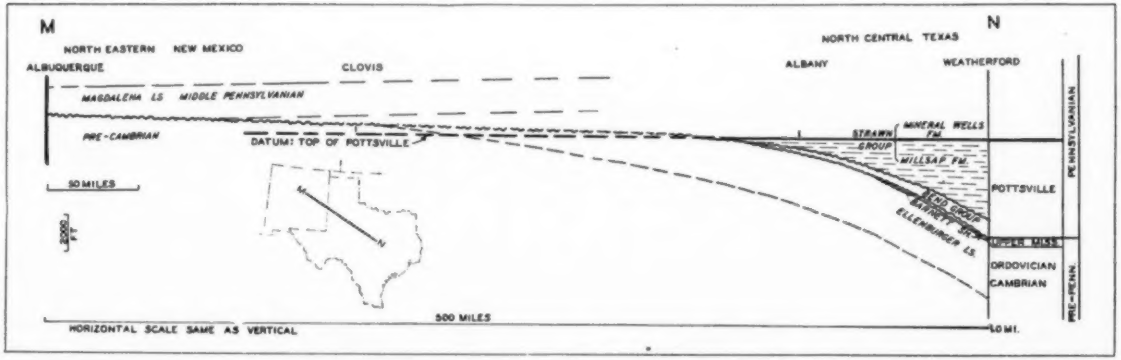


FIG. 12.—Northwest-southeast stratigraphic section across northeastern New Mexico and northern Texas. Location of section shown by line MN in Figure 1. Referred to top of Pottsville as datum.

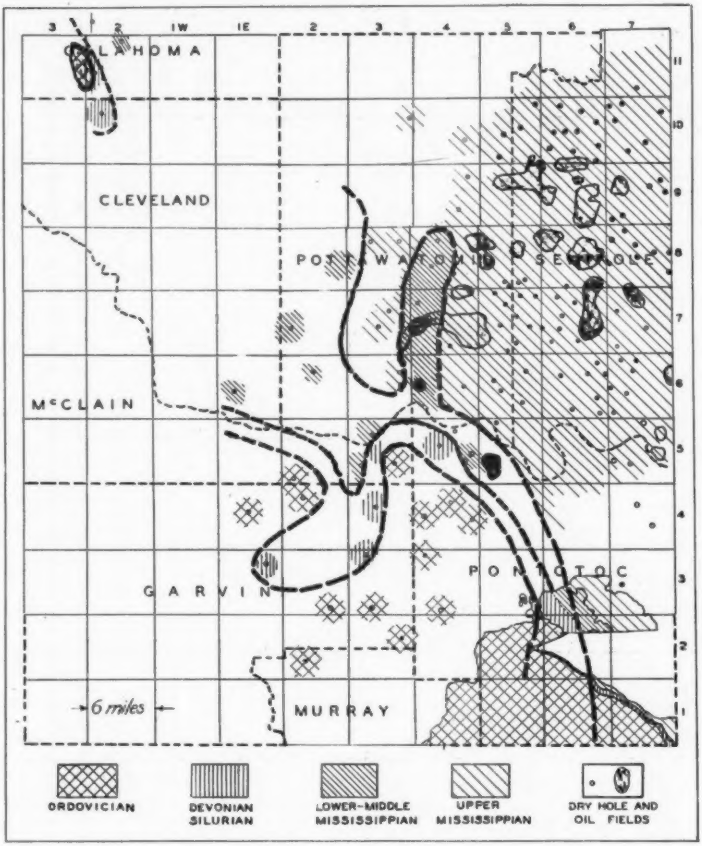


FIG. 13.—Map showing formations underlying Pennsylvanian in south-central Oklahoma.

states area and the Mid-Continent states area where younger sediments conceal the Pennsylvanian, and its basal contact will be known only through future deep drilling.

Figure 14 shows the critical geologic sections in the western states and the correlations used in this paper. Generalized stratigraphic cross sections from west to east are shown in Figure 15 and Figure 16.

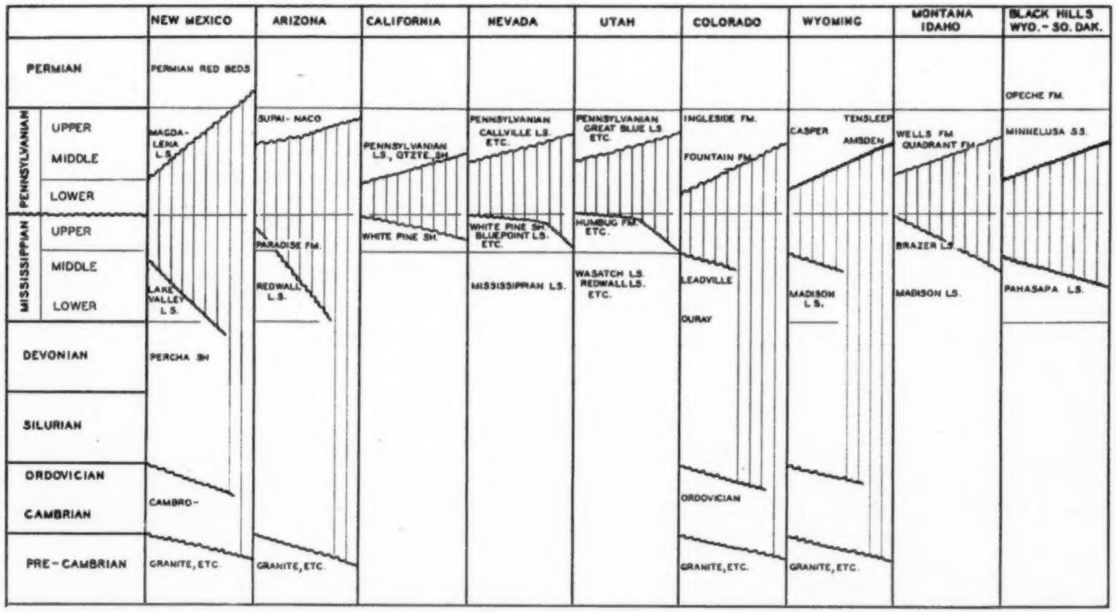


FIG. 14.—Correlation chart of formations adjacent to basal Pennsylvanian unconformity in western states as used in this paper. (Area 5 in Figure 1.)

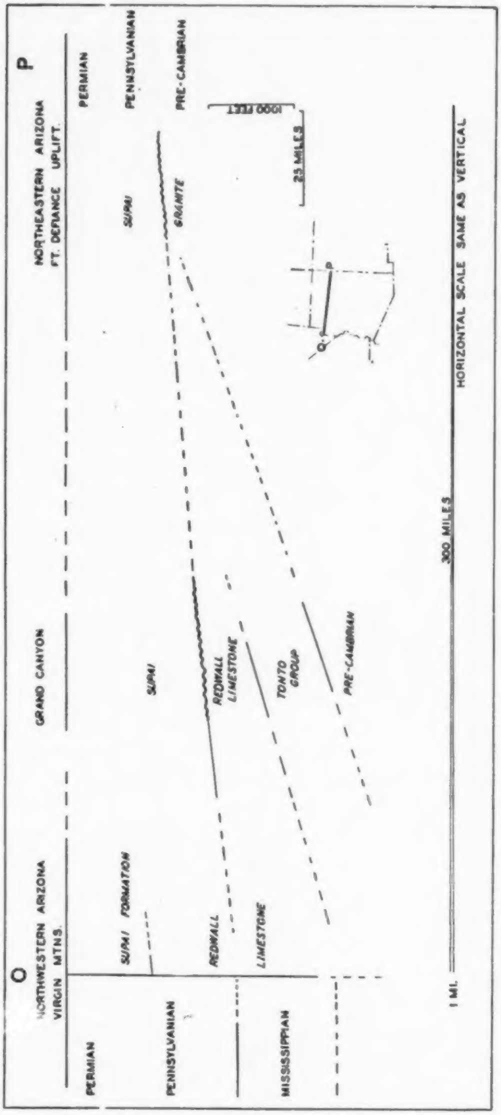


FIG. 15.—Generalized stratigraphic cross section across northern Arizona into northwestern New Mexico. Datum plane is top of Supi formation. Location of section shown by line *OP* in Figure 1.

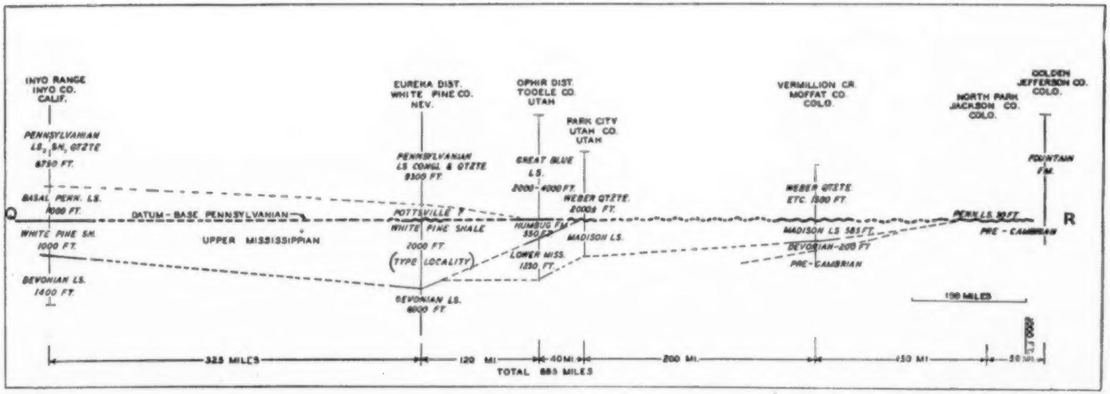


FIG. 16.—Generalized stratigraphic cross section from California to central Colorado. Datum plane is base of Pennsylvanian. Location of section shown by line *QR* in Figure 1.

POTTSVILLE FORMATION

Figure 17 shows the area (shaded) where sediments of Pottsville age are found in the United States. It also shows by 500-foot contours the original thickness of the Pottsville sediments. The contours are based on the itemized thickness of the Pottsville as found in the geologic literature; more than one thousand references have been used. Where the control is good, the measurements are recorded from the top to the base of the Pottsville, the contours are solid, and in the intervening areas where the Pottsville is partly or wholly eroded the contours are dashed or dotted. The information shown in the stratigraphic cross sections is here shown in plan in so far as it applies to the Pottsville.

The control of thickness in the Appalachian states area is good and definitely indicates the thickening toward the southeast. The curving of the isopachous lines around the south side of the Nashville dome is shown in the Appalachian states and in the Mississippi Valley states and indicates a connection at one time at the south end of the Appalachian Mountain range, of Pottsville sediments. The faunal and lithologic character and the isopachous maps indicate that the Pottsville sediments of Texas were at one time connected with the Pottsville sediments of Oklahoma and Arkansas; and that at one time the Pottsville sediments of Texas, Oklahoma, and Arkansas were connected with the Pottsville of Illinois and western Kentucky. In the same manner, the great thickness of the Pottsville in Alabama is comparable with the great thicknesses of the Pottsville of eastern Oklahoma and the Arkansas Valley of Arkansas, and indicates that they were at one time connected. The thickness of the Dimple and upper Tesnus formations of the Marathon Mountain region and of the Solitario uplift of West Texas fits into the general contour pattern very well and marks the southwestern end of the known Pottsville. Further detailed paleontologic work may determine several formations in the Rocky Mountain states to be Pottsville in age, and eventually may develop a U-shaped pattern for the Pottsville deposition. The writer believes the evidence sufficient to justify the conclusion that the Pottsville sediments were at one time continuous from New York to West Texas and that they were deposited in a sea advancing along a front continuous throughout this distance. The writer does not know how far beyond these limits the deposition continued, but further work will undoubtedly develop extensions in both directions.

Throughout the area underlain by Pottsville sediments the evidence, almost without exception, points to a thinning toward the northwest

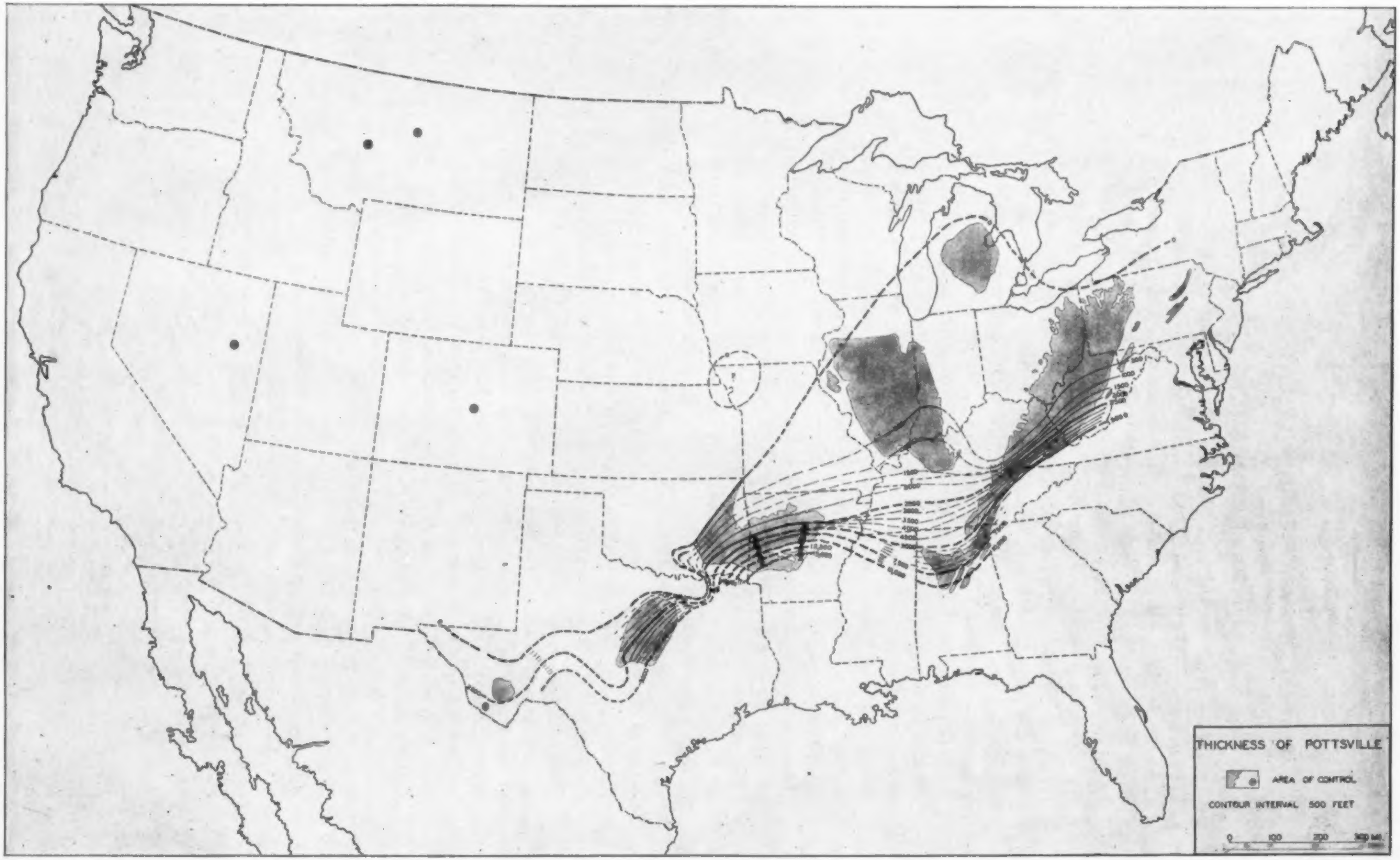


FIG. 17.—Map showing areas in United States where sediments of Pottsville age are found (shaded). Total thickness of Pottsville indicated by 500-foot contours.

and north. This northwest thinning is, also, nearly everywhere caused by a northwest overlap of progressively younger Pottsville beds. The closer spacing of the contours around the edges shows this overlap to be more rapid there than farther inland. The isopachous contour pattern is similar to that on maps showing the depths of the water off the present coast of the Gulf of Mexico, the wide spacing representing the area above the continental shelf and the closer spacing representing the area above the steep descent of the ocean floor into the ocean depths.

The Pottsville wedge, as it might be termed, is relatively thin as shown in the cross sections. The maximum thicknesses on the southeastern edge range from 5,000 to 9,000 feet, or approximately 1½ miles. The thickening of the Pottsville toward the south and east is not uniform, as already described. The thickening from the 0 contour to the 1,000-foot contour occurs in a distance of 250 miles, or at an average rate of 4 feet per mile, and the thickening from the 1,000-foot contour to the 8,000-foot contour occurs in 100 miles, or at an average rate of 70 feet per mile. Each occurrence farthest south and east is thickest.

UPPER MISSISSIPPIAN ROCKS

Figure 18 shows the extent (shaded area) and thickness of the rocks of Upper Mississippian age in the United States. The isopachous contour interval is 500 feet and each line connects points of equal interval between the base of the Upper Mississippian and the base of the overlying Pottsville formation. Solid contours represent good control or areas where both the overlying Pottsville and basal Upper Mississippian are present, and dashed and dotted contours represent inferred thicknesses in areas where the data about the Upper Mississippian are incomplete or absent. The contours are based on the thicknesses of the Upper Mississippian sediments as found in published information.

The rocks of Upper Mississippian age thin out toward the north and west in the east half of the United States and toward the east in the western states, resulting in a U-shaped occurrence around an area extending from Minnesota on the north to West Texas and New Mexico on the south.

The correlations used are shown in Figures 2, 7, 10, and 14. The Upper Mississippian of the north Appalachian states is definitely correlated with the Upper Mississippian of Alabama and Tennessee. The rocks of this age in Alabama and Tennessee have been correlated with the Upper Mississippian rocks of the Mississippi Valley, which in turn can be correlated with the Upper Mississippian rocks of Arkansas,

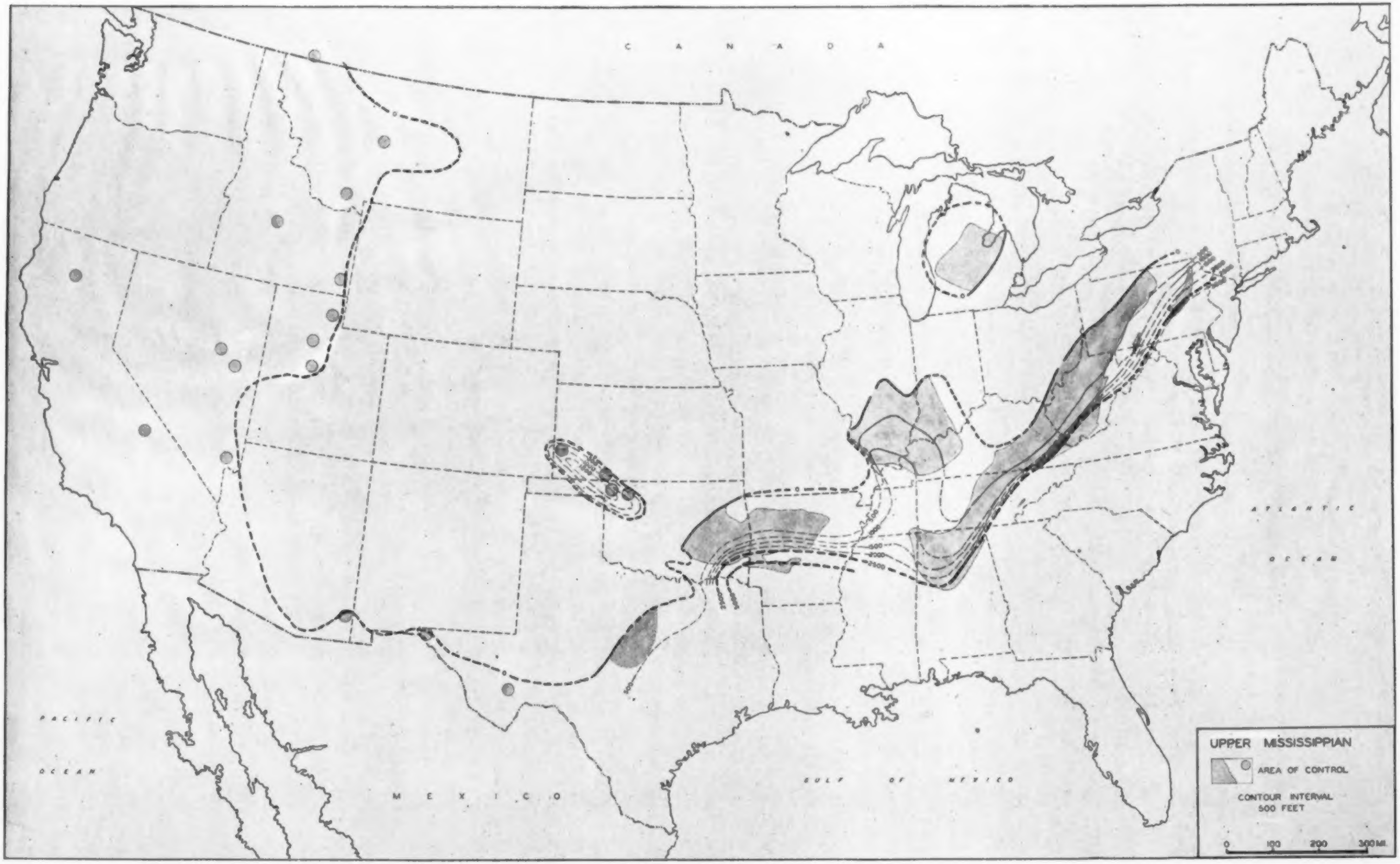


FIG. 18.—Thickness of rocks of Upper Mississippian age in United States shown by 500-foot contours. Shaded areas represent known occurrences of Upper Mississippian rocks, and round shaded areas represent isolated, small outcrops or bore holes.

Oklahoma, and Texas. The Upper Mississippian of the western states is separated from the equivalent rocks of the central and eastern states by long distances, but at several places definite fossil evidence and similar lithology make certain the time equivalence of the western deposits of Upper Mississippian age with those of the central and eastern states.

Throughout the area underlain by sediments of Upper Mississippian age the evidence almost universally points to a thinning of these sediments toward the center of the U. The evidence also seems to indicate conclusively that the chief cause of the thinning in this direction is the progressively deeper erosion and removal of progressively older formations in this direction in pre-Pennsylvanian time. A part, however, of this inward thinning of the Upper Mississippian formations is undoubtedly due to non-deposition and erosion within the Upper Mississippian, and it is believed that this cause is of secondary importance. The writer believes a reasonable conclusion is that the erosion of the Upper Mississippian was continuous from the Appalachian states around the south side of the U to the western states, that this erosion was progressively deeper as the central part of the United States was reached, and that the eroding sea front which advanced inward from the periphery of the country was also the site of the deposition of the Pottsville sediments as previously described.

The Upper Mississippian rocks in any area may be considered as a wedge in cross section. The wedge is relatively thin, the thickening ranging from almost nothing to 3,000 feet in 100-200 miles. The rate of thickening, however, of the Upper Mississippian rocks east of the Rocky Mountains is not uniform, as the thickening from almost nothing to 1,000 feet occurs in a distance of 100 miles, or at an average rate of 10 feet per mile, and the thickening from 1,000 feet to 6,000 feet occurs in 50 miles, or at the rate of 100 feet per mile. This change in rate is probably in part due to an originally greater thickness of the Upper Mississippian sediments in this area and in part to a more rapid sinking of the sea floor along the periphery of the continent. The Upper Mississippian rocks are thickest at the south and east limits of the area according to the records of occurrences east of the Rocky Mountains.

Of considerable interest is the recent discovery below the Pennsylvanian of a remnant of Upper Mississippian rocks in northwestern Oklahoma and southwestern Kansas with a maximum thickness of 1,500 feet. This can be explained best as a protected outlier of Upper Mississippian in a relatively local syncline on the major continental arch.

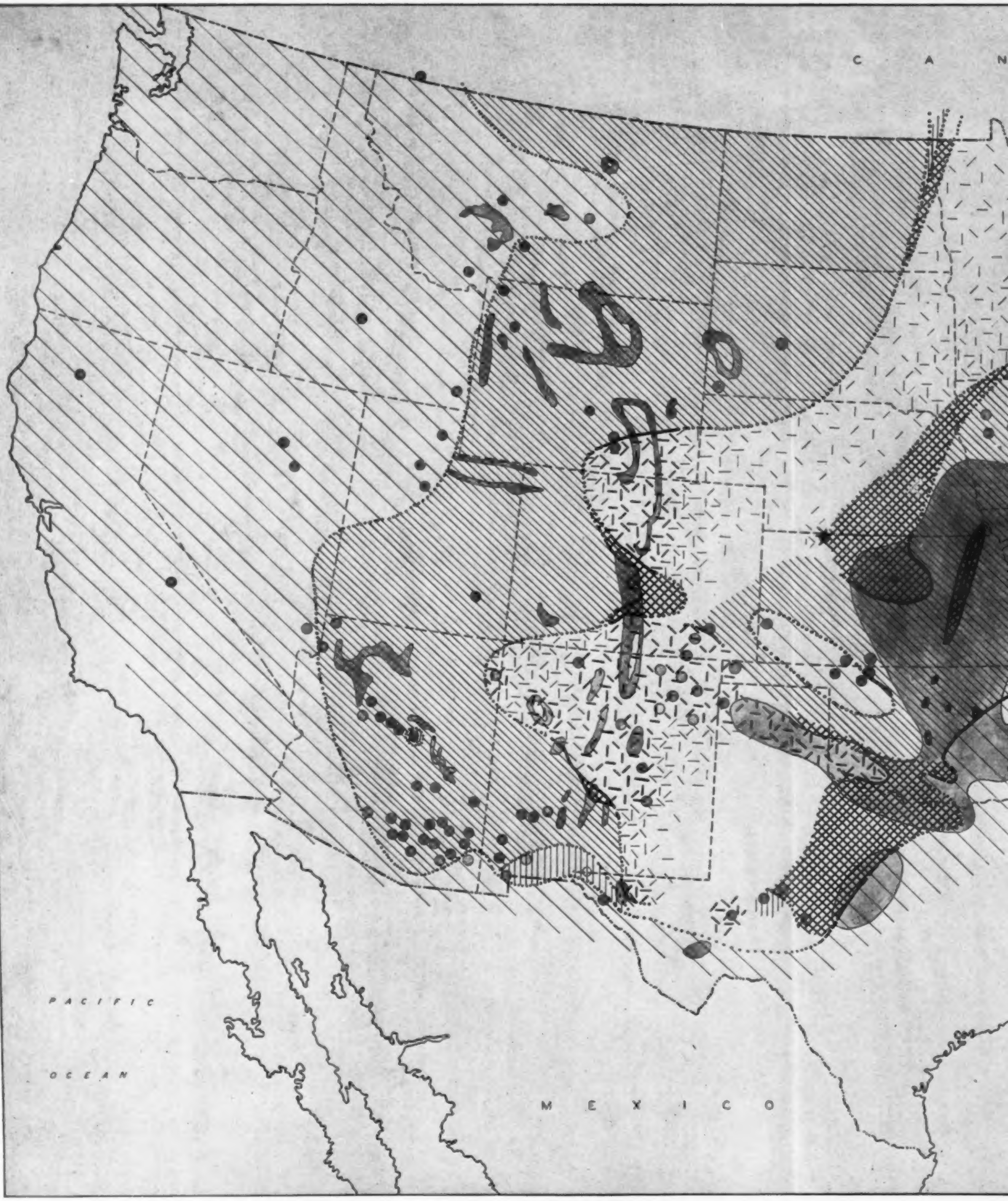
It also indicates that the original occurrence of Upper Mississippian rocks was much wider than the previously known distribution.

The Pottsville and Upper Mississippian rocks cover much of the same area and both wedge out toward the north and west in the east half of the United States. The Pottsville, however, thins out chiefly because of overlap, the youngest Pottsville being found farthest north and west, and the Upper Mississippian thins out chiefly because of erosion at the top, the youngest members being found farthest east and south. In other words, the hiatus or time interval represented by the unconformity separating the Pottsville from the Upper Mississippian increases toward the north and west in that part of the United States which lies east of the Rocky Mountains. The Pottsville of the western states is not well known, but the Upper Mississippian, of which an increasing amount is being found, evidently represents the same progressive erosion except that the time interval or hiatus between the Pennsylvanian and pre-Pennsylvanian formations increases toward the east.

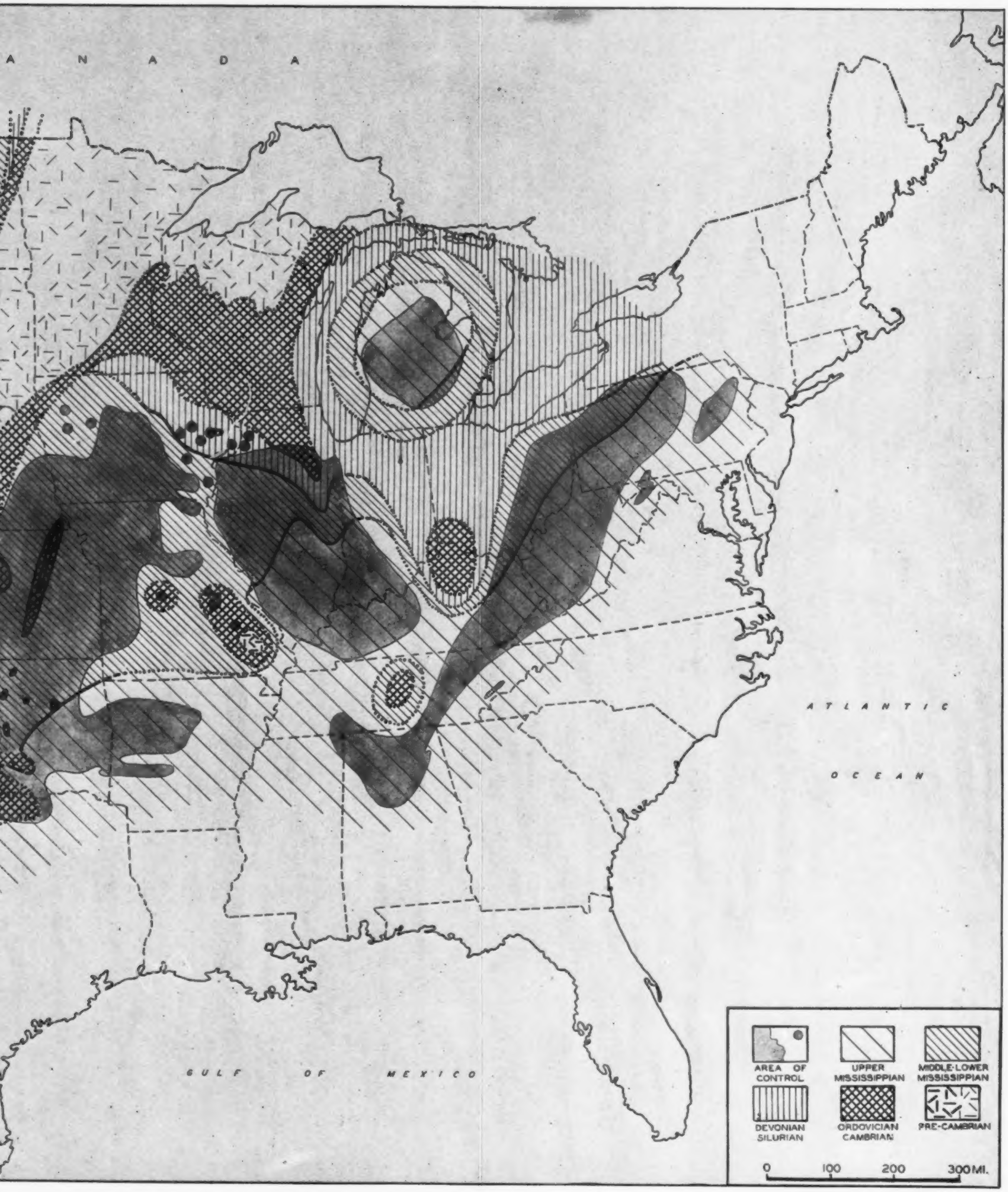
In order to develop the ideas herein presented, the writer has been forced to take sides on many controversial questions of correlation and stratigraphy. The maps are therefore subject to local revision from time to time as these problems are solved and as new facts are obtained. Many of the differences of opinion about correlation do not involve more than 500 feet of sediments, which is less than one contour interval on the isopachous maps. Areas of thick sediments of questionable correlation are not ordinarily large.

PRE-PENNSYLVANIAN AREAL GEOLOGY

Plate 1 is a map showing the areal geology of the United States at the beginning of Pennsylvanian deposition, or the areal geology of the United States as the Pennsylvanian sea expanded across it. This map may also be considered as the areal geology of the United States if the Permian and Pennsylvanian sediments were removed and post-Permian deformation eliminated. It should be noticed that the time of the beginning of Pennsylvanian deposition varies in a direction normal to the isopachous lines shown in Figure 17, and that the areal map shown on Plate 1 does not necessarily represent the areal geology at any fixed time. Thus, when erosion had exposed the Ordovician rocks in northern Illinois, the middle Pottsville was probably being deposited in southern Illinois and Kentucky and the Appalachian states were completely buried by early middle Pottsville sediments.



Pre-Pennsylvanian areal geology of United States, or areal geology of United States if Permian and Pennsylvanian formations were rem
exposures or drill holes.



ons were removed prior to any post-Permian deformation. Shaded areas represent areas of control, small circular shaded areas showing small

This map is a compilation of all of the information available to the writer. In those areas where the basal Pennsylvanian contacts are described from surface occurrence, the control is good; in those areas where the information about the pre-Pennsylvanian is determined from bore holes and well records, the control depends on the number of wells drilled and is continually increasing due to the exploration for oil, gas, and water; in those areas where the Pennsylvanian has been removed and the older rocks are exposed, the determination of the age of the rocks cropping out in early Pennsylvanian time is certain only where the last pre-Pennsylvanian formation, the Upper Mississippian, is present. The shaded areas on the map represent areas of control or areas where information is available. The contact lines are solid in areas of good control and dashed or dotted in areas of little or no information and where their direction and location must be inferred.

Of the pre-Pennsylvanian formations the Upper Mississippian has been shown to have a U-shaped occurrence around a center extending from southeastern New Mexico to Minnesota, seemingly a southward extension of the pre-Cambrian shield of Canada. The Middle and Lower Mississippian rocks, the Devonian and Silurian, and the Ordovician and Cambrian systems all tend toward the same occurrence and are located progressively inward toward the axis of the U. Unconformities within these systems and post-Permian overlaps obscure the relations in many places. The net result, however, is to leave a low, broad anticline with an axis extending from southeastern New Mexico to Minnesota and beyond into Canada. The pre-Permo-Pennsylvanian erosion of this anticline or geo-arch exposed pre-Cambrian rocks along the crest and progressively younger formations along the flanks, the different systems tending toward a concentric U-shaped pattern around the axis.

Each of the pre-Pennsylvanian formations thins out toward the axis of the geo-arch. This is caused partly by overlaps, non-deposition, and unconformities within and between the different systems, but it is also caused by progressively deeper removal of sediments as the axis of the arch was approached by pre-Pennsylvanian erosion. This is further evidenced by the consistent presence of characteristic Cambro-Ordovician sand grains and heavy mineral suites in the lower part of the Pennsylvanian and their absence in the Upper Mississippian formations.

Detailed maps showing the nature of the data upon which the pre-Pennsylvanian areal geologic map (Fig. 18) is based and showing the evidence of the overlapping Pennsylvanian sediments are Figure 9,

which shows an area in southeastern Iowa, Figure 13, which shows an area in south-central Oklahoma, and Figure 19, which shows an area in western Indiana.

PRE-PENNSYLVANIAN FOLDING

The plane of unconformity at the base of the Pennsylvanian system was probably a gently arched, relatively smooth surface, the axis following the more resistant pre-Cambrian rocks between New Mexico and Minnesota. This surface may be used as an approximate datum plane which permits the use of the map shown in Plate 1 as a structure map of the United States at the beginning of Pennsylvanian deposition. The contacts indicate the strike, and the relations of inliers and outliers indicate the direction of dip.

The continental arch extending from New Mexico to Minnesota is the dominant structural feature of such an interpretation. On it lesser anticlines and synclines were formed. Of the anticlines the more prominent were the Laramie arch in southeastern Wyoming and northeastern Colorado, which is undoubtedly related to the Barton arch of western Kansas; the Amarillo fold, which possibly extended as far west as northwestern New Mexico and undoubtedly extended as far east as the Arbuckle Mountains in Oklahoma; the Nashville dome in Tennessee; the Cincinnati arch in Kentucky and Ohio; the LaSalle anticline in eastern Illinois; the Nemaha granite ridge in Kansas; and the northwest-southeast folds in the eastern Ozark region of Missouri. The Michigan basin and the low area in northwestern Oklahoma represent two of the prominent synclinal areas at this time. Upper Mississippian outliers were preserved in both of these synclines.

In those parts of Oklahoma and Kansas where underground exploration for oil and gas has been most extensive, minor folds have been found which were formed at this time. In fact, nearly all of the oil pools in this area where oil is produced from rocks of Ordovician age ("Wilcox" sand, et cetera) were folded at this time. Examples of these include the pre-Pennsylvanian folds in the Cushing, Blackwell, Tonkawa, Garber, Oklahoma City, and Seminole district oil pools in Oklahoma and the Voshell, Valley Center, Augusta, El Dorado, and Raymond pools of Kansas. In some of these fields, erosion was sufficient to remove completely the Mississippian rocks and locally allow the Pennsylvanian sediments to rest directly on rocks of Ordovician age. Many of these pre-Pennsylvanian local folds were also related to faulting and were the sites of later Pennsylvanian and post-Permian recurrent folding

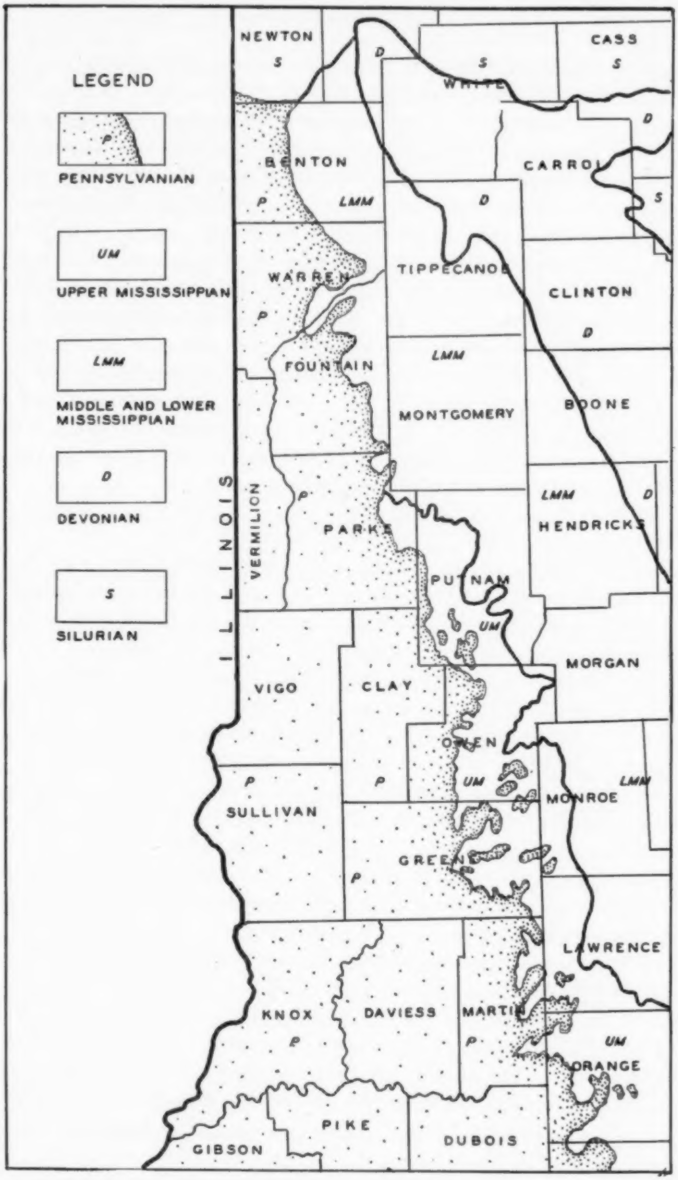


FIG. 19.—Areal geologic map of part of western Indiana, showing overlapping of Pennsylvanian sediments. Adapted from geological map of Indiana in "Petroleum and Natural Gas in Indiana," by W. H. Logan, *Indiana State Dept. of Conservation Division of Geology* (1920).

resulting in a steepening of the dips with depth. The folding of such oil fields as Robberson, Healdton, Hewitt, Wichita Falls district, and Cooke County, all in the Red River district of southern Oklahoma and northern Texas, which permitted Upper Pennsylvanian sediments to rest directly on Ordovician and older rocks, probably represents post-Pottsville folding and erosion which removed the earlier Pennsylvanian deposits as well as those of pre-Pennsylvanian age. In fact, it is probable that in the Mid-Continent states the major structural disturbance of the Pennsylvanian occurred later than the earliest deposits of Pottsville age, or within the Pottsville. This is placed approximately at basal Winslow, middle Atoka, and basal Strawn time and is obviously to be observed only along the east side of this area where these formations are present. Other periods of uplift and erosion occurred later in Pennsylvanian time and these are stratigraphically important in the western parts of Kansas and Oklahoma, where their extent and nature are gradually becoming known through deep drilling.

SOURCE OF PENNSYLVANIAN SEDIMENTS

Keith[1] has shown that the central arch which has been described, and which he terms the "Continental backbone," was persistent throughout Paleozoic history. The question arises as to how much material was eroded from the arch after Mississippian deposition and prior to the advance of the Pennsylvanian sea. Plate 1 shows the Middle and Lower Mississippian as overlapping the Devonian, the Silurian, and the Ordovician, and resting on pre-Cambrian granite in several areas on both sides of the arch. The Middle and Lower Mississippian formations west of the axis are correlated, on the basis of fossils and lithology, with the Middle and Lower Mississippian formations east of the axis. This, together with the relatively short distance separating them, leaves the reasonable conclusion that rocks of Lower and Middle Mississippian age were once present across the arch and that they are now absent along the crest because of post-Mississippian erosion.

The distance separating the occurrences of rocks of Upper Mississippian age on either side of the arch is considerably greater. The correlation, however, of the Upper Mississippian of the western states with that of the Mid-Continent states seems to be definite both as to fossils and lithology. The recent discovery of thick limestones of Upper Mississippian age in northwestern Oklahoma indicates the presence

[1]Arthur Keith, "Structural Symmetry in North America," presidential address, *Bull. Geol. Soc. Amer.*, Vol. 39 (1928), pp. 321-85.

there of a pre-Pennsylvanian syncline in which an outlier of Upper Mississippian rocks was protected from erosion and buried by the Pennsylvanian sediments. It further indicates the much wider original occurrence of rocks of Upper Mississippian age than has heretofore been suspected, with a consequent removal of large quantities of Upper Mississippian material from the higher parts of the arch. The outlier of Upper Mississippian rocks in the southern peninsula of Michigan, 200 miles beyond its main occurrence, is further evidence of a much more widespread original occurrence of these rocks in pre-Pennsylvanian time than at present, and is further evidence for reasoning that large quantities of material of Upper Mississippian age were removed from the central and northern states during the period of erosion preceding deposition of the Pennsylvanian.

Much material of Devonian and Silurian age was undoubtedly removed by erosion at this time in the area extending from Minnesota to New York. In the western states, the Devonian generally overlaps the Silurian in approaching the "continental backbone," and the Devonian is in turn overlapped by the Mississippian, so that very little if any Devonian and Silurian material was eroded at this time from the west side of the arch.

The Ordovician and Upper Cambrian were possibly connected across the arch in Minnesota. The thick Ordovician in eastern North Dakota is relatively near the eastern Minnesota and Wisconsin occurrences on the east flank of the arch. In the same manner it is reasonable to believe that there was a connection at that time of the Ordovician of southern Kansas and northern Oklahoma with the Ordovician of central Colorado, and of the Ordovician of the Bend arch of Texas with the Ordovician of the El Paso region of West Texas and New Mexico. The conclusion seems reasonable, therefore, that there was a considerable amount of Ordovician and Cambrian material eroded at that time, particularly in the northern states east of the arch.

In addition there was uplift and erosion of lesser amounts of pre-Pennsylvanian sediments from the Nashville and Cincinnati domes, the Ozark uplift, the Nemaha ridge, the Arbuckle-Amarillo fold and other lesser folds in post-Mississippian and pre-Pennsylvanian time.

The time of the erosion is further evidenced by the presence in the basal Pennsylvanian sands of Oklahoma, Kansas, Missouri, Iowa, and Illinois of grains of sand typically found in the Cambro-Ordovician sandstones of the northern states and of the Arbuckle region of Oklahoma.

It is concluded, therefore, that sediments in large amounts were removed from the central part of the United States or the "continental arch," and probably from central Canada, during the time intervening between Upper Mississippian and Lower-to-Middle Pennsylvanian time, and that these sediments were moved outward from this source and constituted a substantial part of the sediments of Lower and possibly Middle Pennsylvanian age. The orderly deposition of these sediments in the expanding Pennsylvanian sea was interrupted and contaminated by material derived from relatively local uplifts and sources such as the Wichita-Arbuckle Mountains in Oklahoma, the Cincinnati and Nashville domes in Ohio, Kentucky, and Tennessee, and by other relatively local disturbances such as Appalachia and Llanoria in areas now covered by Cretaceous and younger sediments.

RELATION OF CERTAIN FOREIGN FAUNAS TO MIDWAY FAUNA OF TEXAS[1]

JULIA GARDNER[2]
Washington, D. C.

ABSTRACT

Two faunal provinces existed throughout the Tertiary, a north temperate and boreal province, and a warm-water Tethys which included northern India, the Mediterranean region, and northern Africa. In the northern province the Senonian and Danian of the Upper Cretaceous are dominantly calcareous and are unconformably overlain by the basal Eocene, made up for the most part of sand and clay. In the Tethyan province, both the Upper Cretaceous and the basal Eocene are represented by impure limestones. At no locality in the boreal province does the combined Danian-basal Eocene section greatly exceed 600 feet, but in the Tethyan province in India a maximum thickness of 2,300 feet of basal Eocene has been determined, unconformably overlying 90 feet of trap, the trap in turn covering 300-400 feet of upper Danian.

The Midway fauna of Texas is clearly allied to the homogeneous biota which inhabited the warm and warm-temperate shores of the Gulf of Mexico and as far south as Brazil, and less definitely a part of the more heterogeneous biota originating in the inshore waters of the old Tethyan sea.

The widespread orogenic movements which marked the close of the Mesozoic raised most of the present land masses above the level of the sea. Marine deposits at the close of the Cretaceous and the beginning of the Tertiary are rare, localized, and, for the most part, thin. In the Eastern Hemisphere, at the close of the Cretaceous, two faunal provinces were already defined, and continued to exist during most of the Tertiary, (1) a north temperate and boreal province and (2) a warm-water Tethys which included northern India, the Mediterranean region, and northern Africa, and which extended westward in the Cretaceous to Mexico, and in the Eocene apparently to Jamaica.

In the northern province, the late Cretaceous deposits, the Senonian and Danian, are chiefly calcareous, with bands of dark flint. The base of the Eocene is very generally marked by a conglomerate of rolled pebbles and fossils from the underlying or near-by chalk. Both the pebbles and the fossils are commonly scarred by the attacks of boring organisms and are stained with glauconite. The basal Eocene deposits,

[1]Manuscript received, October 14, 1930. Published by permission of the director, U. S. Geological Survey, Washington, D. C.

[2]U. S. Geological Survey.

the Paleocene[1] of the European section, in marked contrast to the deposits of the underlying Danian, are chiefly sand and clay. In the Tethys province, the lithologic contrast is much less marked, and both the Upper Cretaceous and the basal Eocene are represented by impure limestones. The deposits of recognized Danian age are fewer than those of the basal Eocene, and none of them was deposited during environmental conditions very closely approximating the conditions which prevailed during the deposition of the Midway formation of Texas.

Though the position of the Danian was for many years a subject of controversy, the work of the Danish geologists, particularly of Ravn[2] and Ødum,[3] has stabilized the section and has established the Danian at the top of the Cretaceous.

The standard Danian section in Denmark is chiefly a coccolithic or bryozoan marl, probably deposited in cool, clear water. Ravn,[4] whose work on the Danian faunas is generally accepted, believes that at least 21 per cent—possibly as much as 33 per cent, or a very considerable number—of Danian species were already living in the Senonian, and he believes this regardless of a difference in facies. Only a single species, *Lima testis* Grönwall, persists from the Danian to the Eocene. In some localities, the Senonian evidently grades upward without a break into the Danian, but in every observed outcrop the upper surface of the Danian is corroded and separated from the overlying Tertiary by an unconformity. Both Ravn and Ødum attach great importance to the abrupt change in the character of the sedimentation at the close of the Danian and to the replacement of the calcareous deposits of the

[1]Paleocene was introduced by Schimper in 1874 (*Paléontologie Vegetale*, Vol. 3, p. 680), to include the Bracheux sands and the lignitic beds of Soissons. It is now generally accepted by European geologists to include all Tertiary deposits in the London-Paris basin below the London clay and the Cuisien and their time equivalents elsewhere. It is generally distinct lithologically from the later Eocene, and the flora and the fauna, both vertebrate and invertebrate, have their own characters. The lithology records the struggle between the old beaches and the invading sea. The flora indicates on the whole a warm climate, not as dry as that of the later Eocene. The fauna, both the marine and the non-marine, retains some archaic characteristics which disappear at or before the close of the Paleocene. Many European geologists consider the differences which separate the Paleocene from the later Eocene as significant as those which separate the Eocene from the Oligocene, and give the Paleocene equal rank with the Eocene and the other divisions of the Tertiary.

[2]J. P. J. Ravn, "Sur le placement géologique du Danien," *Mus. Min. et Géol., l'Univ. Copenhague communications géol. No. 5* (1925).

[3]Hilmar Ødum, "Studier Daniet i Jylland og paa Fyn.," *Danmarks geologiske Underosgelse*, II, No. 46 (1926).

[4]J. P. J. Ravn, *op. cit.*, p. 34.

Cretaceous by the basal Eocene sand and clay. The only comparable species in the north European Danian and the Texas Midway sections are *Hercoglossa danica* and *Hercoglossa vaughani*. They are members of a group of species of very similar aspect, which was widespread at the close of the Cretaceous and the beginning of the Eocene. Although forms described as *Nautilus danicus* have been reported from all parts of the world, the true *danica* is probably restricted to the Danian of north Europe. It is unfortunate, but evidently true, that a species so conspicuous and of a group so widely distributed should be of little value in exact correlation. Ravn's comment[1] that these animals do not seem to be of great importance in the solution of the problem was based on his wide experience. Aside from this single species, the Danian fauna of the northern province is of no use as a basis for correlation with the Midway section of Texas.

The Tethyan fauna of Danian age best known and best comparable with that of the Midway is that from the *Cardita beaumonti* beds of India, described by Douvillé[2] and referred by him to the upper Danian. These beds have a considerable area of outcrop not only in the Sind, but also across the border in Baluchistan and Afghanistan and westward into Persia. They are overlain by the Deccan trap, and their reference to the Cretaceous is unquestioned. The fauna is of uncommon interest, because it seemingly contains several ancestral types of species and genera of importance and wide distribution in the Tertiary. Among these are *Cardita beaumonti*, a species very similar to *Venericardia bulla* but smaller, with more numerous ribs, and with more pronounced lateral terracing along the primaries; *Volutocorbis indica*, similar to *Volutocorbis texana*, but smaller and more crudely sculptured; the extraordinary *Diploconus*, which resembles an undescribed species from the Eocene of Mexico; *Pseudoliva*, commonly associated with the Eocene deposits of the Gulf Coast; *Cypraea; Eovasum;* and *Cyclamolops*, seemingly a closely related ancestral type of *Calyptrophorus*. No ammonites and no *Inocerami* have been observed and, in the absence of later beds in the same section, the value of the Tertiary elements in the *Cardita beaumonti* fauna might easily be overrated. The latest Cretaceous beds in the Gulf Coast area contain none of the conspicuously precursal forms. In the Tethyan province, however, the section is much more complete. There

[1] J. P. J. Ravn, *ibid.*, p. 32.

[2] H. Douvillé, "Les couches à Cardita beaumonti," *Mem. Geol. Survey of India*, New Ser., Vol. 10, Mem. 3, Fasc. 1 (1925), pp. 1-25, Pls. 1-4. "Les couches à Cardita beaumonti dans le Sind," *ibid.*, Fasc. 2 (1929), pp. 26-73, Pls. 5-11.

are not only the *Cardita beaumonti* beds, presumably of upper Danian age, but separated from them by an unconformity and a hiatus of unknown extent is a section of Hangu shale, with a maximum thickness of 2,300 feet, described by Cox[1] and referred by him to the Paleocene. The Hangu shale, lying approximately 500 feet above the Deccan trap, contains descendants of the *Cardita beaumonti* species more closely allied to the Midway forms than are the ancestral types of the Danian; neither in the Hangu shale nor in the Midway are found the primitive types of Cretaceous aspect such as the early fusoids of the *Cardita beaumonti* beds. The faunas of the Midway and the Hangu shale are, however, not closely allied, for the Hangu shale fauna is typically Tethyan, containing *Campanile* and *Gisortia*, and the Midway sea was evidently open both to the *Calyptrophorus* fauna of the south and to the *Cucullaea* fauna of the north, and the facies is not tropical, but warm temperate. Furthermore, the Hangu sea and the Midway sea were separated by half the circumference of the earth.

On the evidence of the *Mollusca* alone it seems that the Tertiary fauna originated in the Indian Ocean and migrated westward. Cox[2] has indicated, however, that this theory is not supported by the distribution of the nummulites. However, the Danian fauna of the Tethyan province contains several ancestral types, descendants of which migrated widely and flourished in the Paleocene of the Tethyan province and in the Midway of the Gulf region of the Western Hemisphere.

The so-called Paleocene deposits of the Eastern Hemisphere are classed, as are the Danian, in two distinct faunal provinces: (1) the Tethyan, extending westward probably to Jamaica, and (2) a northern Euro-Asiatic province. This north temperate or boreal province was less extensive than the Tethyan and included several isolated basins, which, during their short existence, were filled with deposits of rapidly changing character. In the Anglo-Franco-Belgian basin, the basal Eocene is represented by the marine Thanet sands of England and the non-marine Woolwich and Reading beds, by brackish and fresh-water deposits in France, and probably by the Montian of Belgium and the Tuffeau de Ciply beds, both marine; in Denmark, by the Seelandian.

The northernmost European early Eocene basin from which a fauna has been recovered and studied is the basin in Denmark. The extent of

[1]L. R. Cox, "The Fossil Fauna of the Samana Range and Some Neighboring Areas; Pt. 8, The Mollusca of the Hangu Shales," *Mem. Geol. Survey of India, Palaeontologia Indica*, New Ser., Vol. 15 (1930), pp. 129-222, Pls. 17-22.

[2]*Op. cit.*

this early boreal sea is not well known. It certainly extended over Denmark and southern Sweden, probably northern Germany, and possibly was connected for a short period with the Volga Basin. The fauna recovered from the excavations made for the Vestre Gasvaerk in Copenhagen and studied by von Koenen[1] has served as the check fauna for the boreal province. A thin deposit of glauconitic sand and conglomerate, less than 20 feet thick, containing a fauna similar to that from Copenhagen, was found at a single locality at Klagshamn, Skania,[2] in south Sweden, but erratics of similar material are common in south Sweden and north Germany. The fauna of the lower Syzranian[3] of the Volga Basin has so many elements in common with that of the Copenhagen fauna that some direct intercommunication has been postulated, though the exact migrational route has not been traced. Inasmuch as it also contains a nautiloid of the *Hercoglossa danica* group, it was first correlated with the Danian. The lithology of the Seelandian is typical of the north European basal Eocene, namely, a coarse, glauconitic sand, ordinarily with a basal conglomerate of rolled Cretaceous fossils and chalk. Though the Seelandian fauna includes *Cucullaea*, *Admete*, *Aporrhais*, *Lunatia*, and *Beloptera*, all northern forms, it includes also several species of *Cancellaria* and two of *Murex*, indicating conditions probably somewhat warmer than conditions of the East Sea of to-day, but colder than the Midway waters. The similarity of *Tornatellaea regularis* of the Copenhagen fauna to *Tornatellaea alabamiensis*, of *Ancillaria flexuosa* to *Olivella alabamiensis*, of *Solarium bisulcatum* to *Architectonica planiformis*, of *Dentalium rugiferum* to *Dentalium mediaviense*, though marked, is of no great significance, inasmuch as the common characters are group rather than specific characters. Importance should be attached, however, to the similarity of *Fusus mörchi* and *Levifusus trabeatus*, of *Pleurotoma johnstrupi* and members of the *mediavia* group plentiful in the early and middle Eocene, and of *Voluta nodifera* to *Volutocorbis texana*. These species seem to represent groups widespread but of short stratigraphic range. The occurrence of *Cucullaea*, *Pseudoliva*, and *Propeamussium* in the Copenhagen fauna is also of interest. The dwarfed character of the Copenhagen fauna, resulting, presumably, from poisonous Black Sea

[1] A. von Koenen, "Uber eine Paleocäne Fauna von Kopenhagen," *Abhandlungen der Königlichen Gesellschaft der Wissenschaft zu Göttingen*, Bd. 33 (Göttingen, 1885), pp. 3-128, Pls. 1-5.

[2] N. O. Holst and K. A. Grönwall, "Paleocen vid Klagshamn," *Sveriges Geologiska Undersökning Skrifter*, Ser. C, No. 208 (1907), pp. 1-27.

[3] A. D. Archangelsky, *Dépôts paléocène de la région Volgienne du gouvernment de Saratov et leur faune materialien sur géologie Russlands,* Vol. 32 (1904), pp. 1-207, 12 pls.

conditions, as postulated by Grönwall and Harder, is not very obvious. The Seelandian may, however, have been deposited in a basin with a very small outlet on the west but opening on the east into the East Sea of the early Eocene. The basal Eocene of Klagshamn, Skania, and that of the erratics of south Sweden and north Germany are similar lithologically and faunally to the basal Eocene of Copenhagen and near-by outcrops. *Turritella* is represented in these faunas only by species of small size. However, erratics from the vicinity of Ysted, Skania, contain many Turritellas of the *T. mortoni* and *T. humerosa* groups. Although the source is not known, Grönwall believes that they may be slightly younger than the Vestre Gasvaerk fauna. The general similarity between the Vestre Gasvaerk fauna and the fauna of the Midway, though not remarkable, is certainly more marked than the similarity between the present south Atlantic and Gulf Coast faunas and the fauna of the East Sea.

Deposits from the boreal sea are present also in south Russia, but the exact course and time of the invasion have not been established. Basal Eocene has been reported, however, from the Volga region across Little Russia as far as the Black and Caspian seas to the Crimea and the foot of the Caucasus. The contact between the Danian and the Eocene is exposed on the banks of the Volga, and though more than 1,200 miles from Copenhagen, the faunas contained are so similar that direct communication is implied. The basal Eocene of the Volga, like that of Copenhagen, is coarse, glauconitic sand deposited on the corroded surface of the chalk, and contains fish teeth and detritus from the underlying Cretaceous. The lower Syzranian, as these beds have been termed, grades upward into a fine, micaceous, glauconitic sand, somewhat friable, gray and yellow, very fossiliferous, with most of the fossils preserved only in the form of molds. This fine sand is the upper Syzranian, which has been correlated with the Thanet sands of the Anglo-French basin.

The Montian fauna of Belgium is believed to be the approximate equivalent in time of the Seelandian, though it was deposited in another basin of sedimentation probably separated by a barrier from the fauna of Copenhagen. It occupied the valley of the Haine, a narrow gulf opening near the French border and extending eastward to the vicinity of Mons. East of Mons the deposits are continental, and the Montian fauna itself is less marine than the fauna of Copenhagen or the succeeding Ypresian. It is rich in the smaller gastropods, in brackish water forms such as *Hydrobia*, in the trochoids and limpets, but in spite of the warmer water facies it has less in common with the Midway fauna than with the

fauna of Copenhagen. The pelecypods, however, *Crassatellites* of the *Scambula* type, *Venericardia,* some of the plentiful and diversified lucinoids, and the venerids, suggest the Midway; and *Corbis* may be cited as evidence that the mid-Eocene molluscan fauna of the Paris basin was chiefly derived from the Montian. The most definite connections are *Volutocorbis elevata* Sowerby, a species of the *Volutocorbis texana* group, and *Calyptrophorus,* a widespread and characteristic Eocene genus, evidently excluded from the Copenhagen basin by the low temperature of the water.

The Tuffeau de Ciply beds are slightly lower than the Montian, and their age is not yet determined. Like the Lithothamnium chalk of southern France, they may be proved to be of upper Danian age. The small fauna contained offers little basis of comparison with the Midway.

The Lithothamnium chalk a few miles north of Vienna has also been cited by Kühn[1] and has been referred to the Danian. Kühn correlates with it several isolated outcrops in the Alps and Carpathians and thinks they are the expression of the halt in the retreat of the Upper Cretaceous sea.

A fauna which has much in common with the Montian has been determined from the Garumian of southwest France. It is probable that in early Eocene time the Aquitanian basin and the Pyrenean formed a gulf opening westward. The deposits in the western part of the basin are truly marine; those of the east are non-marine. Almost no record of the molluscan life of the Mediterranean region has been discovered, though some of the limestones are rich in *Foraminifera.*

No deposits as old as the Montian have been observed in England. The Anglo-Franco-Belgian basin in which the Eocene was deposited included all of south England and Belgium and northwestern France. Sediments were brought in by two rivers, one of them flowing east in the London and Hampshire regions, the other flowing north in the vicinity of Paris. On the north, the sediments were chiefly marine; on the south, chiefly continental. The Landenian, the earliest Eocene of the London basin, includes glauconitic sands unconformably overlying the chalk. The upper Landenian is characterized by a silting-up of the shallow seas, and on the Isle of Thanet is the only locality in which the entire Landenian is marine. The fauna of the Thanet sands is boreal and, in contrast to the Montian fauna and that from Copenhagen, it includes the larger bivalves in conspicuous number. Prominent among these are

[1]Othmar Kühn, "Das Danien der äusseren Klippenzone bei Wien," *Geologischen u. Paläontologischen Abhandlungen,* New Ser., Vol. 17, Pt. 5 (1930), pp. 495-576, Pls. 1-2.

Cucullaea and *Ostrea bellovacina*, the latter suggesting in general dimensions and sculptural characters *O. compressirostra* Say. *Nucula* is present; also *Leda*, *Modiola*, a species of *Glycymeris*, *Astarte*, *Protocardia*, and a common *Cyprina*, *Cytherea*, *Panopea*, *Thracia*, and, in very large numbers, *Corbula regulbiensis*. None of these species has any strikingly close analogue in the Midway fauna. The general character of the fauna is, however, the same; that is, it is composed chiefly of a few plentiful species of pelecypods. A closer relation could perhaps be established between the Thanetian and the lower Eocene in Maryland, which also has a cold-water fauna. The predominance of the bivalves over the univalves is cited by Morley Davies[1] as a characteristic of the boreal and temperate faunas from Cretaceous time to the Recent. The differences which distinguish the Thanetian fauna from the Midway are probably due not only to latitude, but also to time. Though the base of the Thanetian is marked by rolled flints stained with glauconite from the chalk beneath, the hiatus is greater than in the Danish and Belgian Cretaceous-Eocene contacts, for in Belgium the Thanetian has been found overlying the Montian and its later age has thus been definitely established.

At some time during the early Eocene, probably the Thanetian, the boreal sea transgressed as far as Kressenberg in Bavaria, leaving a deposit of coarse, fossiliferous, and very glauconitic sand. This fauna contains a nautiloid very closely allied to *Hercoglossa danica*. The outcrop is of great interest, inasmuch as in the lowest beds only the boreal fauna occurs, but higher in the section the gradual invasion of the Tethyan fauna can be traced in the increasingly common occurrence of *Gisortia gigantia*, a typical Tethyan species and genus. *Gisortia* is, however, not represented in the cooler Midway sea, and the later Kressenberg fauna furnishes no direct information about the fauna of the Midway.

The Tethyan fauna lived in the seas of the Indian, north African, and south European provinces, and probably extended as far west as Jamaica. In consideration of the thickness of the formation and of the fauna contained, the most significant outcrop is that of the Hangu shale of the western Sind in north India. The basal Eocene which L. R. Cox of the British Museum has so adequately treated in the *Palaeontologia Indica* far exceeds in thickness any yet observed, and the fauna of his monograph is the most significant yet described.

[1]Morley A. Davies, "Faunal Migrations Since the Cretaceous Period," *Proc. Geol. Assoc.*, Vol. 40 (1929), pp. 312, 315.

At no locality in the boreal province does the combined Danian-basal Eocene section greatly exceed 600 feet, and though the two series are in every observed occurrence separated by an unconformity, the significance of the break has been questioned. In India, on the contrary, a maximum thickness of 2,300 feet of beds, referred by Cox to the Paleocene, has been determined. These beds unconformably overlie 90 feet of Deccan trap, which in turn covers 300-400 feet of *Cardita beaumonti* beds of upper Danian age. Most of the fossils, however, are from a very thin layer of shale, 2-15 feet thick, approximately 500 feet above the trap. Only two species from the *Cardita beaumonti* beds have been recognized in the Hangu shale, namely, the ubiquitous *Mesalia fasciata* and *Cardium inaequiconvexum* Cossmann and Pissarro. Only seven species are common to the Hangu shale and the overlying Ranikot beds, which are also referred by Cox to the Paleocene, though there are several other species that are very closely allied. Although exact correlation of the Hangu shale with the faunas of the boreal province is not possible, Cox believes that the fauna is of Landenian, or possibly Montian, age. *Athleta* (*Volutocorbis*) *daviesi* Cox is very close to *V. texana*, differing, however, in the somewhat more slender outline, more prominent spirals, and the ease with which the axials may be traced upon the spire. The similar *Volutocorbis eugeniae* Vredenburg occurs higher in the series.

In Persia, Arabia, and northern Africa, the basal Eocene is represented chiefly by impure limestones, many of them foraminiferal. There is comparatively little published detailed information, and much of the work has been little more than reconnaissance. Tethyan *Mollusca* of early Eocene age have, however, been recovered in Persia and Arabia. The age of the Libyan series of Egypt has not yet been established. The foraminiferal and the molluscan evidence do not seem to be in accord, but a part, at least, of the basal Eocene is probably included in the Libyan. The Landana and Senegalese limestones are foraminiferal and contain a good echinoid fauna. They evidently represent much of the basal Eocene, but the *Mollusca* are not well known.

A fauna from the Belgian Congo which has much in common with the fauna of the Midway of Texas has been described. Among the allied forms are a small *Calyptrophorus*, *Surcula* (*Corbulospira*), and *Clinuropsis diderrichi*, which strongly suggests *Levifusus trabeatus*, and which is compared by Vincent with *Pleurotoma ampla* from the Montian and *Fusus mörchi* from Copenhagen. *Venericardia landanensis*, of the group of *Cardita beaumonti*, *Nautilus landanensis*, and *Hercoglossa diderrichi*,

TABLE I

TENTATIVE CORRELATION OF MIDWAY FAUNA OF TEXAS AND OTHER REGIONS

	Texas	*Denmark*	*Belgium*	*England*	*France*	*Germany*	*Russia*	*Sind*	*Persia*	*Egypt*	*West Africa*	*Trinidad*	*Brazil*
										Mokattam			
Basal Eocene	Upper Midway		Upper Landenian	Oldhaven and Blackheath Woolwich and Reading beds	Soissons lignite and plastic clay	Glauconitic and ferruginous sands and marls of Kressenberg	Upper Syzranian	Upper Ranikot	Impure limestones	Upper Libyan?	Fossiliferous limestones of basal Eocene age in the Soudan, northern Nigeria, Senegal, Togo, and Landana, and possibly Angola	Soldado formation (Bed No. 2)	Pernambuco beds
		Kerteminde clay	Lower Landenian	Thanet sands	Bracheux sands								
	Lower Midway	Seelandian	Montian		Meudon marl	Well bores and erratics in north Germany	Lower Syzranian	Lower Ranikot		Lower Libyan?			
					Pisolitic chalk								
Upper Cretaceous		Hiatus	Tuffeau de Ciply	Hiatus	Lithothamnium chalk								
								Deccan trap					
								Cardita beaumonti beds	Cardita beaumonti beds				
		Danian chalk	Hiatus		Hiatus	Hiatus	Hiatus						
		Hiatus											
		White chalk	Tuffeau de Saint Symphorien	Trimingham chalk	White chalk	Mucronaten beds	White chalk	Arrialoor					

have more than a generic resemblance to *Venericardia bulla* and *Enclimatoceras vaughani*.

A relation between the Eocene fauna of Togo[1] and that of the Midway of south Texas is indicated by the Togo species, *Turritella adabienensis*, evidently of the group of *T. humerosa*, and by *Volulithes cumeri*, which differs from *Volutocorbis limopsis* chiefly in the more slender outline and the closer spacing of the stronger spirals. *Calyptrophorus* is present; also small Carditas of the general type of *C. beaumonti*, but less inflated. A *Hercoglossa* of the *danica* group, occurring in the basal Eocene both in Landana and the Sokoto beds of Nigeria, earlier caused confusion in correlation. However, in spite of the lithologic similarity of the late Cretaceous and early Eocene limestones, in north Africa, wherever detailed work has been done, a hiatus between the Cretaceous and the Eocene has been established. Though the basal Eocene has been recognized in many areas in north Africa, the presence of an interior sea connecting the Indian Ocean with the Atlantic by way of the Libyan desert is a subject of controversy. The early Eocene seas were widespread over the old African land mass, but whether or not this sea extended toward the east or the northeast has not been determined. The field relations of the Eocene deposits of Nigeria, the marine limestone of the northern province, and the gravel and conglomerate of the south controvert the theory that the Eocene sea was merely the wash of the old continent by the Atlantic Ocean.

The extension of the Tethyan sea westward to Jamaica during Lutetian time is postulated chiefly because of the occurrence of *Velates schmideliana* Chemnitz, which in the Paris basin characterizes the Sables de Cuises, and at Kressenberg and in South Madagascar characterizes the Lutetian horizon. Other significant genera include *Campanile*, *Clavilithes*, two species of *Gisortia*, *Carolia*, and *Corbis*. The middle and South American earliest Eocene faunas, however, are more closely allied to those of the North American Gulf faunas than to the north African. The fauna of the Soldado formation of Trinidad, which includes *Ostrea pulaskensis*, *Ostrea crenulimarginata*, *Cucullaea hartii*, *Calyptrophorus compressus*, and *Turritella nerinexa*, is definitely not only of Midway but of lower Midway age. *Mesalia pumila nettoana* is a link not only with the Midway of Alabama and Texas, but also with the Pernambuco beds of Brazil, from which it was first described, and through *Mesalia fasciata*, a similar species ubiquitous in the Tethyan province, with the basal Eocene of northern Africa and India.

[1]Paul Oppenheim, "Das eocäne invertebraten Fauna des Kalksteins in Togo," *Beiträge für geologischen Erforschung der deutschen Schutzgebiete* (1915).

The Pernambuco beds of Brazil contain a more pronounced Tethyan element than the Soldado. They are notable as the southernmost limit of *Cucullaea*, which is commonly associated with the boreal province. The genus is unknown in the Africo-Asiatic province and is not found in Europe south of Kressenberg. The *Harpa dechordata* of White is a *Pseudoliva; Fusus* (*Serrifusus*) *mariae* is a *Levifusus* of the *trabeatus* group; and *Calyptrophorus? chelonitis* is closely related to *C. compressus*. "*Nerinaea*" *mangurata sagittaria* and *buarquiana* are *Campanile*, one of the most characteristic genera of the Tethyan province. The Turritellas indicate a relation with the Gulf Coast faunas, and the Mesalias are widespread in the Tethyan province. There is no evidence of any Pacific element in either the middle or the South American basal Eocene faunas.

The Midway fauna of Texas is unmistakably a part of the homogeneous biota which lived on the warm and warm temperate shores of the Gulf of Mexico and as far south as Brazil, and is less definitely a part of the more heterogeneous biota originating in the inshore waters of the old Tethyan sea.

The existence of marine deposits of Danian age in either of the Americas has not been established.

SOME EFFECTS OF METAMORPHISM ON CERTAIN DÉBRIS IN SOURCE ROCKS[1]

TAISIA STADNICHENKO[2]
Washington, D. C.

ABSTRACT

The results of microscopic examination and of tests with the microfurnace show that in the fossil and slightly altered deposits of mother rock the optical characteristics of the principal fossil components differ from those of the corresponding component in the recent deposit, although the melting points are found to be distinctly higher.

Source rocks of petroleum[3] include carbonaceous or "bituminous" sedimentary deposits, containing aquatic plant and animal remains, generally of low orders, and the products of their biochemical and geochemical alterations. The organic matter in these rocks varies greatly in content and character, but essentially it is primary in nature, and is only slightly soluble in ordinary organic solvents. When heated, these rocks give off gases and vapors, some of which, when condensed, closely resemble petroleum. In fact, some of the distillates may be regarded as, in effect, artificial petroleums. The qualities and composition of the distillates depend, naturally, in part on the process of distillation.

Through the study of thin sections of source rocks in a microfurnace, some of the effects of heat on the different organic materials in them

[1]Read before the Association at the New Orleans meeting, March 21, 1930. Manuscript received, November 22, 1930. This paper contains results obtained in the "Studies of Source Rocks in the Microfurnace," listed as Project No. 3 of the American Petroleum Institute research program. Financial assistance in this work has been received from a research fund of the American Petroleum Institute donated by John D. Rockefeller, Sr. This fund is administered by the Institute with the coöperation of the Central Petroleum Committee of the National Research Council. The work was done in the laboratories of the U. S. Geological Survey under the direction of David White.

As presented, the paper was illustrated by microphotographs in colors. Owing to the difficulties and cost of reproduction in colors and the comparatively small value of illustrations in black and white, several of the figures have been omitted from this publication.

[2]Research associate, American Petroleum Institute, Research Project No. 3.

[3]David White, "The Carbonaceous Sediments." See W. H. Twenhofel, *Treatise on Sedimentation*, p. 308.

may be easily seen.[1] The most striking change observed is the visible formation of oil. The temperature at which it forms is definite for a definite rock. It differs with the kind of rock, and seemingly according to the stage of natural carbonization.

These rocks differ in physical aspect as well as in chemical composition. In some types little megascopic organic débris is visible, and the organic matter consists mainly, if not almost wholly, of the organic products of the biochemical decomposition of plant and animal materials, originally deposited in solution and now precipitated and hardened in the groundmass. This colloidal organic matter is regarded as ulmic or humic by most chemists. It is the organic binder in the richer source rocks. From this generally somewhat lean type, which may be erroneously termed "amorphous," to the very rich types in which conserved organisms, mainly of aquatic forms, are so plentiful that they may comprise the largest part of the rock, the transition is complete.

The predominant plant remains found in the very rich mother rocks are algal thalli and spores (the Alaska spore rock[2] is an almost pure spore accumulation, as also is tasmanite). The richest Devonian bituminous shales generally contain very many spore exines, many with some fatty micro-algae, though in most of these shales the organic matter is mainly confined to the colloidal groundmass. Such shales extend from central New York southward to Tennessee and westward to Indiana, Ohio, Illinois, Missouri, and Oklahoma. They underlie most of the Appalachian oil sands and parts of the oil fields of the Mississippi Valley and Mid-Continent regions. Some rich deposits of this type are found in New Brunswick, where they are related to oil seepages. The inorganic matter in the source rocks is mainly of terrigenous origin and ranges upward from approximately 3 per cent to 90 per cent or more.

The processes of sedimentation and subsequent alteration of source rock deposits are similar to the processes of coalification[3] ("bituminization") and comprise: (1) The putrefaction or fermentation process, which is biochemical; and (2) the metamorphic process, that is, the chemical and physical alteration produced under geodynamic influences.

[1]See papers from the Geophysical Laboratory, Carnegie Institution of Washington, No. 563; also, Taisia Stadnichenko and David White, "Microthermal Observations of Some Oil Shales and Other Carbonaceous Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 9 (September, 1926), pp. 860-76.

[2]Taisia Stadnichenko, "Microthermal Studies of Some 'Mother Rocks' of Petroleum from Alaska, with Description of the Fossil Plants by David White," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929), pp. 823-48.

[3]David White, "Some Problems in the Formation of Coal," *Econ. Geol.*, Vol. 3 (1908), p. 303.

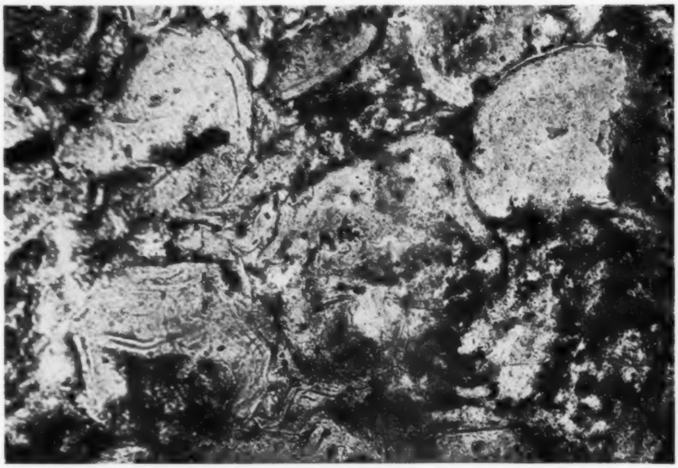


FIG. 1.—Spore deposit from Meade River basin, Alaska (× 80). In ordinary transmitted light.

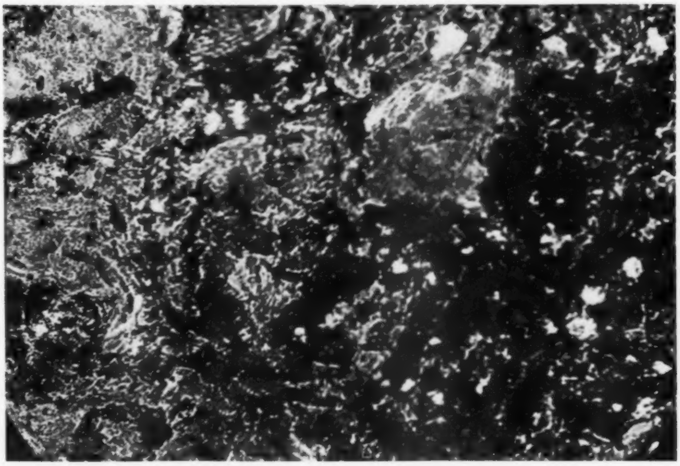


FIG. 2.—Same section in polarized light under crossed nicols with gypsum plate. Anisotropism of spores is well shown.

FIG. 3.—"Balkhashite," a recent deposit from shore of Ala-Kool Bay, Lake Balkhash, Russian Turkestan (× 100). Algal colonies, *Botryococcus braunii*, are barely discernible.

FIG. 4.—Same material heated to 250° C. (× 160). Cell walls are golden amber in color, and dark brown "humic" cell contents of individual colonies are plainly seen.

The extent to which one or the other or both processes have progressed varies from type to type, from deposit to deposit, and from point to point in every deposit. In no deposit have both processes reached completion.

Some of the effects of metamorphism can readily be observed in the organic débris in source rocks. The organic matter of the living plants as ordinarily found is isotropic, whereas most of the fossil organic débris studied exhibits certain anisotropic properties. The examination of the thin sections under polarized light with a gypsum plate reveals the anisotropism plainly (Plate 1, Figs. 1 and 2).

This condition of matter is due to molecular changes in the substance as the result of dynamic stresses to which the plant débris has been subjected after its deposition as a sediment. The change in molecular structure is observed in most of the carbonaceous deposits, including coals and oil shales. It is not permanent. Under the influence of heat the anisotropism gradually diminishes and at temperatures approaching the temperature of melting the substance becomes quite isotropic, as in the case of the living matter.

Two very interesting recent deposits of sapropelite can be used with corresponding fossil deposits to illustrate the effect of metamorphism.

One is found in the Gulf of Ala Kool, a shallow arm of Lake Balkhash in Russian Turkestan. This recent deposit is composed principally of a microscopic one-celled, spheroid green alga, described by Zalessky[1] as *Botryococcus braunii*, and is very similar to, and possibly generically identical with, the genus *Pila*, found in Scotch and French oil shales and in bogheads from Alaska and Kentucky.

After the death of the algae, gases generate and the débris rises to the surface in large, jelly-like, dark green masses, which are driven ashore by the wind. Here fermentation with generation of hydrogen sulphide proceeds until decomposition is arrested, with only partial decay and loss of the fatty matter. Exposed to the air or buried in the shore deposits, the organic matter shrinks somewhat and becomes a yellow-brown, solid, rubber-like mass, with a distinctly waxy odor.

When heat is gradually applied to thin sections (Fig. 3) of this sediment they first change in color, which slowly turns creamy yellow, then golden yellow and orange. At temperatures slightly above 200° C., the algal structure begins to be more evident, and when the temperature reaches 250° C., the algal colonies present in the deposit are well revealed (Fig. 4). Fusion takes place at 380°-390° C. The substance

[1]M. D. Zalessky, *Com. Geol. Russia Bull.* 33, Pt. 2 (1914), p. 306.

volatilizes at about 425°-430° C. In the Scotch oil shale, in which the *Pila* corresponds with the recent *Botryococcus*, the alga melts at 462° C.

Coorongite, another recent sapropel, is described in detail by R. Thiessen[1] as mainly composed of microscopic algae (*Elaeophyton*) closely related to the fatty alga *Reinschia* and referred to the Protococcaceae. When heated in the microfurnace this coorongite algal colony darkens at 225° C. The melted substance gradually turns more and more mobile and boils when it reaches 340° C. Here, also, we find that the corresponding alga of the Australian kerosene shale melts at about 457° C.

As already noted, the colonial alga from the recent deposit of Lake Balkhash is in its structure and mode of growth so similar to the Permian and Mississippian *Pila* of western Europe that it is regarded by paleobotanists as perhaps generically identical. Similarly, the characteristic alga of coorongite, *Elaeophyton*, is so nearly identical with the Paleozoic *Reinschia* that its systematic differentiation is made only because of the great time interval between the present and the Paleozoic. It was at first regarded by Thiessen as generically identical. Further, the detailed study of the materials, both recent and fossil, leaves little room for doubt as to the close similarity, if not identity, in organic composition, of the recent and fossil forms of both algae.

In short, the fatty matter of the cell walls both in the Balkhash deposit and in the recent coorongite not only melts at lower temperatures than in the corresponding fossil deposit, which has undergone a degree of metamorphism, but it also is isotropic, whereas in the somewhat altered (carbonized) mother rock from the Paleozoic, it is birefringent.

It is concluded, accordingly, that the geodynamic alteration (carbonization) of the plant substances results in raising the temperatures of fusion and volatilization and in change in optical characters from isotropic to anisotropic.

[1] "Origin of Boghead Coals," *U. S. Geol. Survey Prof. Paper 132* (1925), pp. 121-37, Pls. 27-40.

BLACK SHALE DEPOSITION IN CENTRAL NEW YORK[1]

EDWARD W. HARD[2]
Ithaca, New York

ABSTRACT

The Devonian black shales of central New York are described. The current theories of black shale deposition are briefly reviewed, and their application to the black shales of central New York is discussed. The conclusion is reached that the type of decomposition rather than the type of organic material determines the bituminous content of these shales and that this particular type of decay existed only where the water was truly saline and toxic conditions were present. Comparatively shallow water seems to have been the environment of deposition.

INTRODUCTION

Eventually the oil fields of to-day will be so depleted that a considerable part of petroleum production will be obtained from bituminous shales. Already used to a small extent, they can not be profitably exploited at the present price of crude oil. Because these shales are in many places the source beds of commercial oil fields, data which may lead to a better understanding of the environment of their deposition are important.

Among the best known and most extensive deposits of this type are the Devonian black shales. These are brown to black, thin-bedded shales, containing iron sulphide and a few layers of calcareous concretions and sandy and calcareous beds. Fossils are generally scarce, though some layers contain innumerable remains. The molluscan fauna is characteristically thin-shelled, denoting a deficiency of calcium carbonate in the water. True benthonic forms are generally absent, but planktonic remains are in places very plentiful. Most of the floral representatives are microscopic, though megascopic fragments of carbonized wood are not uncommon.

Microscopically, the Devonian black shales are composed chiefly of fine silt and a considerable amount of organic detritus, consisting of spores and spore cases, bits of cuticular material, a groundmass of more

[1]Manuscript received, October 30, 1930.

[2]Cornell University. Present address: The Pure Oil Company, Fort Worth, Texas.

or less macerated and decomposed plant and animal matter, and here and there some faunal débris.

Various divergent views have been expressed concerning the exact depositional environment of these shales. Ancient and recent bituminous and carbonaceous sediments have been studied in an attempt to learn more regarding black shale environment and the origin of the petroliferous material. The main purpose of the writer is to endeavor to explain further these interesting and important questions.

ACKNOWLEDGMENT

The writer wishes to express his appreciation to C. M. Nevin, under whose supervision this work was done; he also wishes to thank L. C. Petry, G. D. Harris, A. C. Gill, and D. W. Trainer, all of Cornell, for helpful suggestions made during the investigation.

STRATIGRAPHY OF AREA STUDIED

The bituminous shales considered in this paper are the Genesee, Middlesex, and Rhinestreet of the Upper Devonian. In New York these formations crop out in an area approximately 170 miles long and 30 miles wide, extending from the Chenango Valley at Sherburne westward in a belt across the central part of the state to Lake Erie. The Genesee is found in the entire area; the Middlesex and Rhinestreet are present only west of Seneca Lake (Fig. 1).

South of New York in Pennsylvania, the Genesee has a thickness of 225 feet, but in West Virginia its average thickness is approximately 150 feet. According to Grabau[1] it is absent in Ohio, Indiana, Kentucky, Michigan, Wisconsin, and Illinois, because the Ohio shales, which he believes to be younger, rest disconformably on the eroded surface of the Hamilton. However, Foerste,[2] of the Kentucky Geological Survey, states that fossil evidence unquestionably shows some of the Kentucky black shales to be of Genesee age; and Kindle[3] states that a typical Genesee plant fossil has been found in the Huron shales of Ohio. The Middlesex and Rhinestreet shales probably have their equivalents in some of the black shales of the east central states, though this equivalence

[1] A. W. Grabau, "Stratigraphic Relationship of the Tully Limestone and the Genesee Shale of Eastern North America," *Bull. Geol. Soc. Amer.*, Vol. 28 (1919), p. 947.

[2] A. F. Foerste, "The Silurian, Devonian, and Irvine Formations of East-Central Kentucky," *Kentucky Geol. Survey Bull.* 7 (1906), p. 114.

[3] E. M. Kindle, "The Stratigraphic Relations of the Devonian Shales of Northern Ohio," *Amer. Jour. Sci.*, Vol. 34 (1912), pp. 209-210.

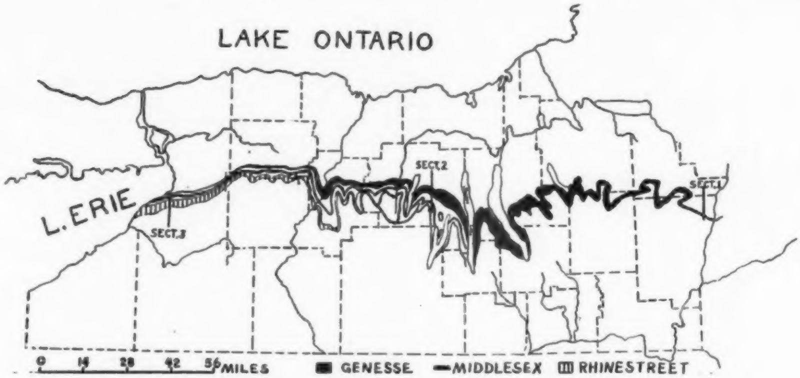


FIG. 1.—Outcrops of Genesee, Middlesex, and Rhinestreet in New York state.

has not been definitely determined. The writer, however, does not attempt to correlate these formations outside of New York state.

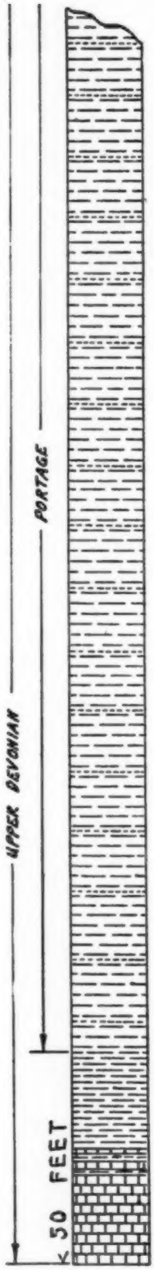
Figures 2, 3, 4, and 5 show the relationship and stratigraphy of the Genesee, Middlesex, and Rhinestreet shales. These sections are located at east-west intervals of approximately 80 miles.

LABORATORY STUDY OF BLACK SHALES

Characteristic samples of the formations were collected at several places on the outcrop, for destructive distillation tests, loss on ignition, and thin sectioning. Wherever possible, samples of the Genesee were collected 4-7 feet above the youngest distinctly calcareous layer of the Tully or above the contact where it was sufficiently abrupt. This horizon was chosen because it was comparatively easy to locate, uniform, and most accessible. However, it was impossible to be certain that no calcareous layers were included in the samples, as in many places such layers were extremely difficult to detect; therefore, some of the results may be slightly inaccurate. For the purpose of comparison three samples were taken at other horizons. When these were tested, the results were very similar to those from the samples taken near the base. Samples of the Middlesex and Rhinestreet were taken from the middle of these formations.

The retort used in distilling the shales was similar to that recommended by the U. S. Bureau of Mines.[1] It was carefully insulated with

[1] L. C. Karrick, "A Convenient and Reliable Retort for Assaying Oil Shales for Oil Fields," *U. S. Bur. Mines Rept. of Investigations 2229* (1921).



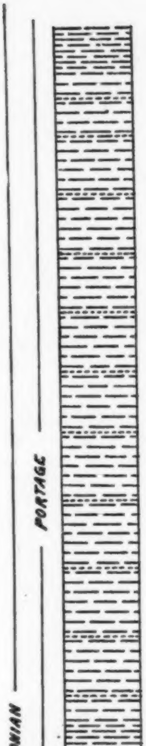
Ithaca shale 500 feet — Interbedded blue-gray and olive shales, with a few flags and sandstone lenses with maximum thickness 8 inches. Plentiful remains of brachiopods, lamellibranchs, gastropods, and crinoids, in individual layers

Sherburne flags 250 feet — Soft gray shales, with thin layers of dark shales and thin flags,—the latter more numerous near the top. Fossils are rare and consist of a few brachiopods and plant remains

Genesee shale 30 feet — Sandy, thin-bedded black shale, containing a few plant remains and fish plates

Tully limestone 39 feet — Fine-grained, sandy, gray-black limestone, with plentiful fossils

FIG. 2.—Geologic section at Smyrna, 5 miles west of Chenango Valley.



Rhinestreet shale 15 feet	Sandy, thin-bedded, grayish black shale, containing a few plant remains and fish plates
Cashaqua shale 225 feet	Olive-gray shales, with a few thin flags, sandstones, and calcareous concretions. Gastropods, cephalopods, lamellibranchs, and crinoids are plentiful
Middlesex shale 15 feet	Sandy, thin-bedded, grayish black shale, containing many carbonized plant stems, and a few worm trails
West River shale 65 feet	Dark gray shale with a few beds of black shale. Upper layers sandy. Calcareous concretions common. Few fossils
Genundewa limestone 15 feet	Three 10-inch layers of dark fossiliferous limestone. *Styliolina fissurella* are very plentiful
Genesee shale 90 feet	Thin-bedded black shale, with a few horizons of calcareous concretions. Few fossils
Tully limestone 6 feet	Dark gray-black limestone, with many fossils

FIG. 3.—Geologic section at Gorham, midway between Seneca and Canandaigua Lake.

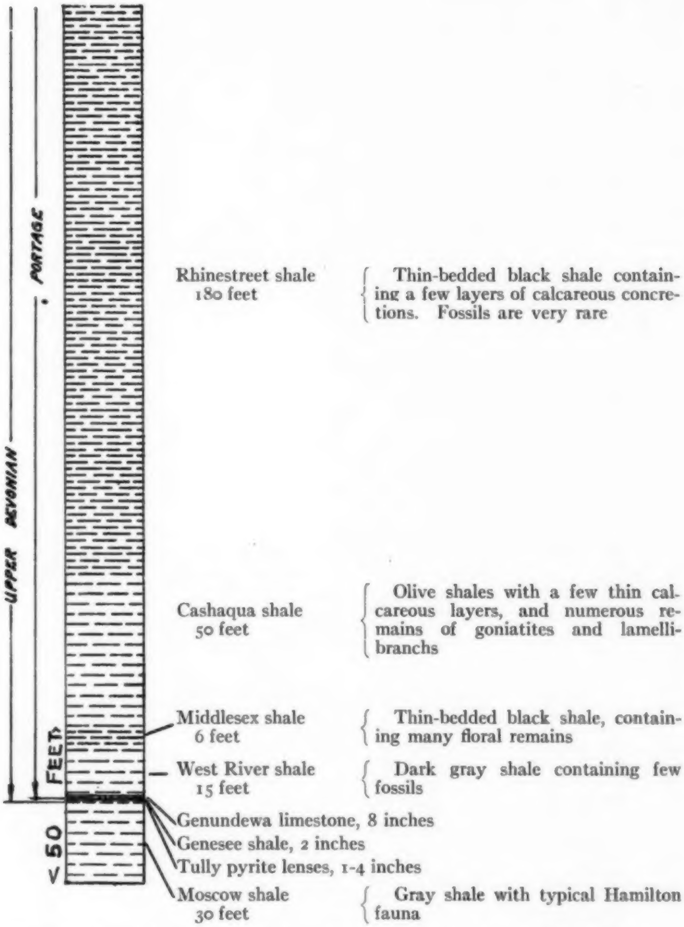


FIG. 4.—Geologic section at Eighteen Mile Creek, 12 miles south of Buffalo.

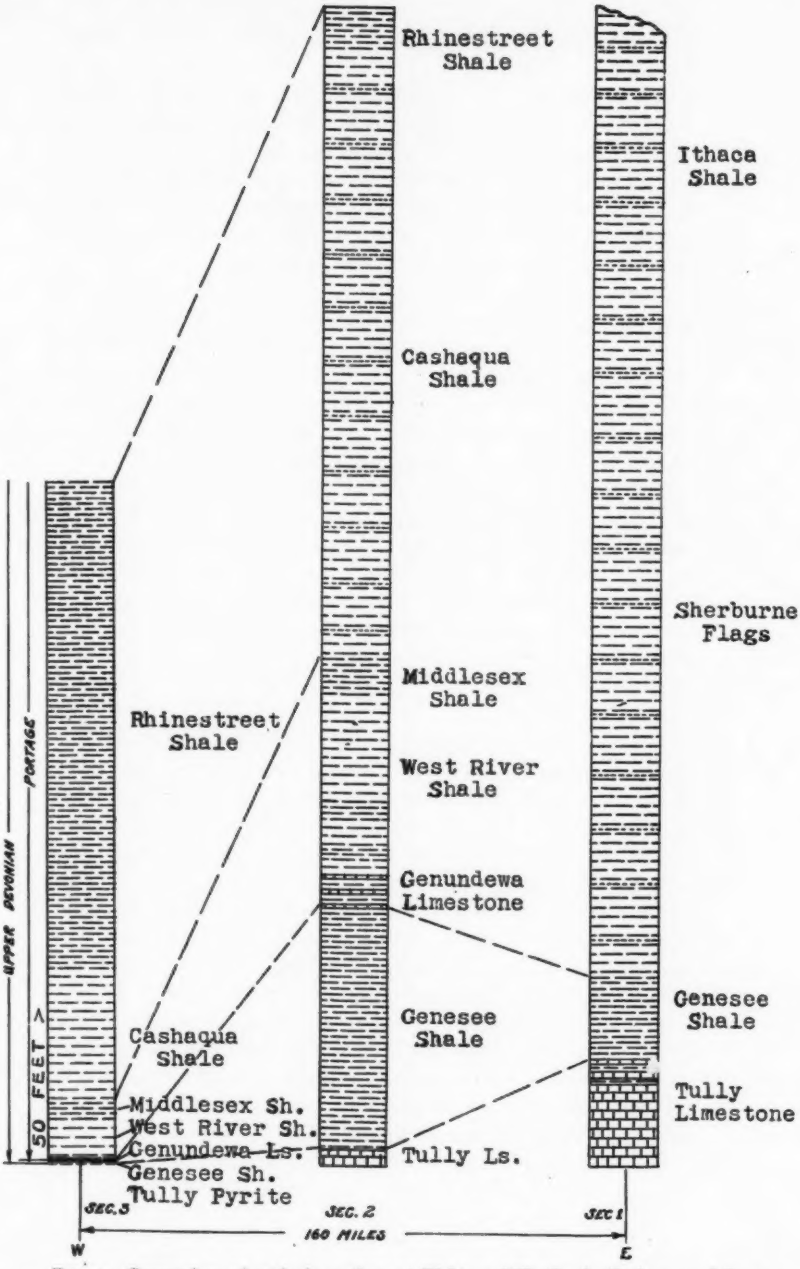


FIG. 5.—Comparison of geologic sections at Eighteen Mile Creek, Gorham, and Smyrna (Figs. 4, 3, and 2).

asbestos board to reflect the heat upon the top of the retort and prevent the condensation of any oil at this point. The contact surfaces of the lid and retort were carefully ground with fine valve-grinding compound to make a gas-tight fit. These surfaces were re-ground, and the retort was tested for leakage before each run. A paste of powdered litharge and glycerin was used to seal all other joints and connections. Figure 6 shows diagrammatically the results of the distillation tests.

Microscopically, the Genesee is composed of angular quartz grains having an average diameter of 0.03 millimeter, a groundmass of macerated organic material, and a few oval bodies that resemble spore cases.

The groundmass is composed of brown, macerated, organic matter with small fragments of carbonized plant material. These fragments are somewhat concentrated in layers containing many quartz grains. The groundmass seems to remain unchanged throughout the extent of the Genesee, except that in the western part it becomes slightly more reddish and contains a few small nodules of pyrite.

Scattered throughout the groundmass, with their long directions parallel with the bedding planes, are a few somewhat flattened oval bodies. These are thin-walled, light brown, and vary from 0.022 to 0.1 millimeter in width and from 0.1 to 0.6 millimeter in length. In general, they are smaller and more flattened in the western part of the Genesee than in the eastern. These bodies are very probably spore cases.

The Middlesex and Rhinestreet shales differ, microscopically, from the Genesee only slightly. They are composed of the same constituents, but the groundmass is somewhat darker and more reddish, and the "spore cases" are more numerous, thicker-walled, and flatter. Except for a slight decrease westward in the number of quartz grains, these shales remain the same throughout their extent.

At the exposure in Eighteen Mile Creek, some of the lower beds of the Middlesex contain small dark round objects scattered on the bedding planes. Microscopically, these proved to be disks of a dark reddish substance, approximately 0.6 millimeter in diameter and 0.04 millimeter in thickness. No structure was visible. What these represent is not known, but it is thought that they may be resin-like substances that have been liberated from plant tissue, or possibly large spores.

In summarizing the results of the laboratory work, it would seem from ignition tests that there is no consistent increase in the volatile content of the Genesee to correspond with the increase in the amount of petroleum, as this formation is traced westward. Microscopically, the

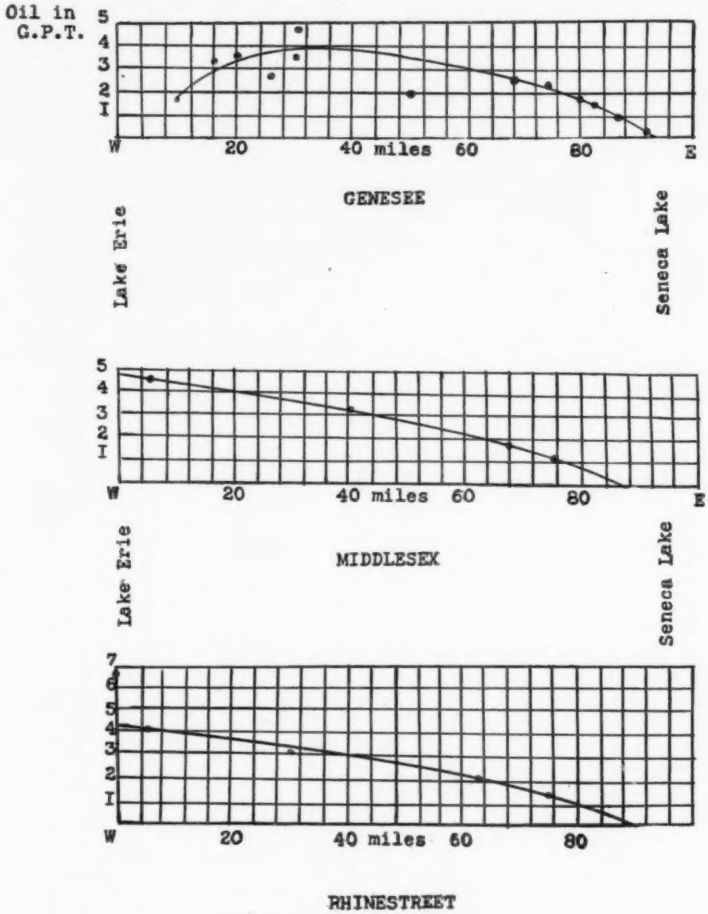


FIG. 6.—Distillation curves.

Genesee, Middlesex, and Rhinestreet differ only slightly from each other, and each formation remains the same throughout its extent. These facts indicate that, though the petroleum of these shales is probably derived from one or more of the organic constituents, another factor closely related to its origin is probably the degree as well as the type of

decomposition of the organic material. Incidentally, the percentage of sulphur in the shales seems to be somewhat proportional to the oil content.

The oil curves show that environment favorable to the preservation of the bituminous material began at approximately the same lateral horizon for all three black shales. But, though it consistently became more favorable westward during the deposition of the Portage (Middlesex and Rhinestreet), it reached an optimum for Genesee deposition approximately 40 miles east of the western limit of this formation.

It is noteworthy that the petroleum distilled from these black shales is deep red and that its specific gravity is very similar to the average specific gravity of the oil produced from the commercial fields in the southwest part of the state.

DEPOSITIONAL ENVIRONMENT OF BITUMINOUS SHALES

In general, bituminous shales may be divided into two classes, (1) those of great thickness and wide distribution and (2) those that are comparatively local, although they may have considerable linear extent. Bituminous shales have the following characteristics: general, though not invariable, "paper-thin" bedding; a large content of iron sulphide and organic sulphur; a general scarcity of faunal remains and an absence of true benthonic types; plentiful planktonic forms, as graptolites, pteropods, et cetera, in individual layers; and a few layers of sandstone, conglomerate, or coal, interstratified with the shales. As far as the writer can ascertain, the beds of sandstone or conglomerate are associated with those shales that are only local in extent. Any theory to explain the depositional environment of bituminous shales should consider the foregoing characteristics.

Clarke[1] believed the Genesee shale was deposited in waters of great depth (600 meters or more) and stagnancy, analagous to the present Black Sea. The sediments of this sea, as described by Andrussow, and quoted by Clarke, consist of

> very fine sticky black mud, with rich separation of FeS, abundant remains of planktonic diatoms, and with fragments of quite young lamellibranchs. .... dark blue muds; FeS is here in less measure, but in richer quantity are separation of minutely grained $CaCO_3$, making at times thin bands.

Pompeckj also used Andrussow's results in the interpretation of the black Jurassic shales of Bavaria.

[1] J. M. Clarke, "Naples Fauna in Western New York," *New York State Mus. Rept. 57*, Mem. 6, Pt. 2 (1903), pp. 199-201.

It is obvious that, although such conditions might produce a sediment similar to the Genesee, the deposit would be only local in extent.

Schuchert[1] states that widely distributed black shales probably originated in closed arms of the sea, *cul-de-sacs*, and explains the planktonic remains as the result of occasional storms. Deposits of small extent would be caused by the filling of holes in the sea bottom. Defective circulation and oxygen deficiency would characterize both conditions. It is doubtful if *cul-de-sacs* ever existed in sufficient size and number to explain the black shale deposits of the Devonian. If storms were sufficiently intense to carry planktonic forms to the ends of these bays, why were the beds not disturbed? Schuchert also suggests that some bituminous shales may be the result of "Sargasso seas," but, as such seas are little known, this hypothesis does not seem important.

Ruedemann[2] considers the most essential requisite of bituminous shale deposition to be tranquillity, not depth, of water. He believes that the graptolite shales of northern New York indicate "a zone between the agitated water, where the coarser sediments are deposited, and the dead or currentless water of the deep sea." This theory explains the linear extent of these deposits, but it is not applicable to those black shales that have a wide distribution.

Ulrich[3] does not believe that enclosed or stagnant conditions are necessary for black shale deposition, but thinks that the Paleozoic graptolite shales were deposited in troughs connecting large bodies of open water, or in "broad shallow pans," and that marine life existed in the upper layers of water as long as they remained uncontaminated. He also suggests that the fossil characteristics might be explained by a cool climate, which rendered "the shores inhospitable for contemporaneous littoral and benthonic life."

Grabau and O'Connell[4] have concluded that the graptolite shales of southern Sweden were deposited in comparatively shallow water, as they rest on an eroded surface, and that similar shales of southern Scot-

[1] C. Schuchert, "The Conditions of Black Shale Deposition as Illustrated by the Kupferschiefer and Lias of Germany," *Amer. Phil. Soc. Print 54* (1915), pp. 259-69.

[2] R. Ruedemann, "Stratigraphic Significance of the Wide Distribution of Graptolites," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), p. 234.

[3] E. O. Ulrich, "Revision of the Paleozoic Systems," *Bull. Geol. Soc. Amer.*, Vol. 22 (1911), p. 358.

[4] A. W. Grabau and M. O'Connell, "Were the Graptolite Shales, as a Rule, Deep or Shallow Water Deposits?" *Bull. Geol. Soc. Amer.*, Vol. 28 (1919), pp. 959-64.

land were mud deposits in lagoons and on the flood plain of a large delta, where periodic high tides carried in the graptolites.

At present, black muds are accumulating on the east shore of the Baltic. These deposits occur in bays of the mainland and islands and in sounds between the islands and the mainland. The water circulation is feeble, and the tides are weak. These deposits may eventually become black shales, of local extent only.

Goldman[1] describes a similar deposit in Chesapeake Bay, the black muds being in deep holes in the bay, in the deeper parts of the tributary river bottoms, and along the shore of the bay between the sandy shore deposits and the more scoured central channel. The extent of this deposit is not comparable with that of many bituminous shales.

Grabau[2] cites a third illustration in the Bay of Dantzig on the southern coast of the Baltic Sea, where Vistula River, after draining the comparatively flat country of Poland and southeastern Prussia, deposits a dense black mud, which contains a large quantity of organic material. This mud, locally termed pitch, covers an area of 615 square miles on the bottom of the bay. As in the two previous illustrations, if this mud eventually becomes bituminous shale, it will be local in extent.

Moore[3] believes that the thin but persistent horizons of black fissile shale in the Pennsylvanian indicate deposition in "extremely shallow water, with sunlight promoting plant growth and aiding in partial decay, and with too little depth for circulation and effective wave or tidal agitation."

After considering the characteristics of bituminous shales and the theories of their deposition, the writer believes it obvious that bituminous shales are deposited under differing conditions, and that no single theory satisfactorily explains all types of these deposits. However, although extremely deep and stagnant conditions are not essential to black shale deposition, an acid and toxic environment, with tranquil water and oxygen deficiency, is necessary.

Before discussing the depositional conditions during the Genesee, Middlesex, and Rhinestreet, it is necessary to locate the source of these formations. Sedimentary material ordinarily becomes coarser toward its source. As previously mentioned, the eastern part of the Portage is

[1]Marcus I. Goldman, "Black Shale Formation in and About Chesapeake Bay," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8 (1924), pp. 195-201.

[2]*Op. cit.*, p. 153.

[3]R. C. Moore, "Environment of Pennsylvanian Life in North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 5 (May, 1929), p. 465.

composed of considerably coarser material than the western. This indicates that the sediments of this series originated in a land mass on the east. This belief is strengthened by the fact that the eastern Portage (the Sherburne-Ithaca series) contains scour channels and ripple marks which definitely show that the current bringing in the sediments came from the east.

As the Genesee also becomes coarser eastward and grades into the Sherburne flags, and as another source of the sediments does not seem logical, it is probable that the Genesee also originated in the east. Moreover, south of New York, in Pennsylvania and West Virginia, the same indications are present, proving that this was not a local condition.

Most of the theories about bituminous shale environment require tranquil water to account for the "paper-thin" bedding of the shales. This desired tranquillity is generally explained by supposing that deposition occurred in either very deep or very shallow water, or in partly protected basins. However, when the fact is disregarded that the beds may have been compressed to one-fifth or less of their original thickness, it is quite possible that any moderate agitation would not be permanently reflected in the shales, for the colloidal character and fineness of the material would cause it to remain in suspension during periods of disturbance until the water again became tranquil. When this material was redeposited, of course, some differential settling occurred. This explains the repetition of thin layers of fine quartz grains in these shales. If scour channels are retained they are extremely difficult to observe, for it is almost impossible to trace an individual lamination for any distance. Moreover, as the bedding is generally due to the layers of fine quartz, the difference in cohesion above and below a scoured surface is probably not sufficient to overcome cohesion between individual laminations, and this scouring is not apparent even on weathered surfaces. No doubt the water must often have been tranquil, but conditions of absolute tranquillity are evidently not essential.

In a discussion of the depth of water, depth being closely related to tranquillity, the faunal remains of the different formations should be considered. As previously mentioned, the Genesee fauna increases in amount and variety westward. An increase in numbers may be due in part to the small amount of sedimentary material in the western part of this formation; therefore, the faunal remains may be relatively plentiful. In addition, the organisms existing in the west during Tully time, and preserved in the Tully pyrite, are dwarfed and depauperate, denoting very unfavorable conditions; those in the eastern area are fully devel-

oped and evidently existed in a favorable environment. Therefore, it is possible that though forms surviving these western conditions might have become sufficiently acclimated to withstand the toxicity of the Genesee, those in the east were destroyed immediately. However, it is doubtful whether this is sufficient entirely to explain the relative profusion of forms.

The fossils found in the western part of the Genesee may be divided into two general classes, (1) the bottom-living forms and (2) the surface and free-swimming forms. The first class is represented by thin-shelled brachiopods which probably existed under very unfavorable conditions. At Seneca Lake, the remains of these forms are few, but westward they increase greatly in number to a maximum approximately 40 miles east of Lake Erie, beyond which they decrease, though they continue to be common where the shale is only about a foot thick. Farther west it was impossible to obtain sufficient material to ascertain the relative faunal abundance.

As brachiopods are thought to have been best developed in comparatively saline water, the increasing scarcity of forms toward the east was very probably due to fresher water in this direction. This supposition is further strengthened by the environment in the overlying Portage which, as far west as Seneca Lake, was probably only slightly brackish, because scour channels and current ripple marks show the activity of brackish or fresh-water currents that were distributing the sediments. This fact indicates that the water was deeper, less contaminated, and more saline in the west than in the east, and strengthens the supposition that the Genesee came in from the east.

Most of the surface and free-swimming forms are small cephalopods and pteropods which similarly increase in number westward and reach a maximum at approximately the same locality as the brachiopods. West of this, the cephalopods are very scarce, though the pteropods are plentiful. From the existence of these types, it is inferred that the surface layers of the western part of the Genesee sea were comparatively free from contamination, were somewhat salty, and, in general, were thicker than those of the eastern part.

Although it is possible to explain the westward increase in fauna partly by the fact that the amount of débris consistently decreased in this direction, the water being thus less contaminated, this does not explain the maximum profusion of both types at the same locality, and the decrease farther west. It is thought that where the faunal remains

are most profuse, the water was deepest and that west of this place (40 miles east of Lake Erie) it again became shallower.

This general westward deepening is also suggested by the establishment of a profile of equilibrium between the amount and size of material brought in and the speed of the current. This profile sloped away from the source of sediments, and, as its degree of slope was determined by the type of the incoming material and the strength of the currents, the profile established during Genesee deposition was probably somewhat flat. Therefore, there was not a great difference between the water depths of the eastern and western parts of the Genesee sea, though there was probably a sufficient change to account for the variation in fossil profusion. Because the eastern part of the Genesee grades into, and is covered by, the very shallow-water sediments of the Sherburne flags, the Genesee sea was not very deep unless there was a considerable subsequent uplift, a condition which it is undesirable to assume. In addition, the Genesee sea probably had approximately the same depth as the Tully limestone, and as there are dwarfed and depauperate cephalopods and other free-swimming organisms in the Tully pyrite, indicating that even the surface layers of the water in this area were contaminated, this was probably not very deep.

Another fact indicating the depth of Genesee deposition is that the Genundewa limestone, overlying the western part of the Genesee, contains numerous scour channels and other evidences of disturbed shallow-water conditions. This limestone shows that at the end of Genesee deposition the source of the sediments changed and the water cleared sufficiently to permit an abundant fauna to exist. These periods were brief, however, and black-shale conditions quickly returned, though after the last layer of the Genundewa had been deposited, the conditions were less toxic, and the sedimentary material was somewhat coarser than during typical Genesee deposition, thus allowing some of the Genundewa fauna to remain.

Because the Genesee is so closely related to shallow-water sediments, it is concluded that this formation also was deposited in relatively shallow water.

The Middlesex and Rhinestreet shales were probably deposited in water of approximately the same depth as the eastern part of the Genesee sea, for their fossil content is extremely small; therefore, even the surface layers of the water must have been somewhat toxic. Moreover, both the Cashaqua shale lying between these formations, and the Hatch shale above, are essentially shallow-water sediments, and, as in the

Genesee, any considerable bottom warping is improbable. It is noteworthy that, excluding the Genundewa limestone, the faunal profusion decreases from the Genesee to the Middlesex. This suggests that the water was becoming shallower and fresher, and that the upper layers were becoming more contaminated. These conditions, therefore, are in agreement with the fact that Middlesex and Rhinestreet begin a considerable distance farther west than does the Genesee. There was not much deposition during the Middlesex, because this formation has a maximum thickness of only 35 feet, and thins to 6 feet in approximately 75 miles.

After the deposition of the Middlesex, the land mass at the east was uplifted, a large amount of comparatively coarse material was carried into the sea, and the water cleared, permitting the existence of a profuse fauna. These conditions lasted during Cashaqua deposition; then sedimentation changed, and black-shale conditions returned, forming the Rhinestreet. The consistent westward thickening of the Rhinestreet is probably due to a large supply of material of this type and to the sinking of the sea bottom during deposition; hence, the profile of equilibrium remained constant. At the close of the Rhinestreet deposition, another strong uplift occurred, sedimentation became more vigorous, and the water cleared.

It is important to note that at approximately the lateral horizon of Seneca Lake, the following phenomena occur. The profusion of fossils and the content of sulphur and iron sulphide in the Genesee increase considerably; the bituminous content of this formation appears; the Tully limestone is replaced by a series of pyrite lenses; the Genundewa limestone begins; the Portage fauna changes from a littoral to a deep-water assemblage; the lithological characteristics of this formation become more varied with a tendency toward finer material; and the Rhinestreet and Middlesex appear. Some of these phenomena have already been discussed, and were found to denote a change from comparatively fresh, shallow water to more saline, deep water. Inasmuch as this change occurs at approximately the same locality throughout the entire series from the Tully to the top of the Portage, it is suggested that at this locality a "hinge" line existed in the geosynclinal basin.

If this zone of warping existed during Genesee time, the bituminous content of this shale was probably directly related to the environmental conditions in the western part of the Genesee sea, and it has been previously suggested that these conditions differed from those on the east in depth and salinity. Because the Middlesex and Rhinestreet were prob-

ably deposited in water comparable in depth with the eastern Genesee sea, and because these formations contain a relatively large amount of bituminous material, it seems that the origin of material of this type is directly related to the salinity of the water rather than to its depth. As has been suggested, bituminous matter is due to the type as well as the amount of decomposition of the organic material, and, as there are two main types of decomposition, physical and bacteriological, it is believed that the latter results in the formation of the petroleum. This is also indicated by the fact that the percentage of sulphur and iron sulphide in the shales is, approximately, directly proportional to the amount of petroleum contained. Therefore, it seems that, in this locality, the particular type of bacteriological decay essential to the formation of bituminous matter could occur only during somewhat saline conditions.

SUMMARY

The Upper Devonian bituminous shales of New York were deposited in comparatively shallow water; the source of sediments was on the east. During the deposition of the series, of which the bituminous shales are a part, a definite zone of demarcation existed between the shallow and comparatively fresh water of the east and the slightly deeper and more saline water of the west. The bituminous content of these shales seems to be directly related to the type of decomposition rather than to the type of organic material, and this particular type of decay existed only where the water was truly saline and toxic conditions were present.

MINNELUSA FORMATION OF BEULAH DISTRICT, NORTHWESTERN BLACK HILLS, WYOMING[1]

F. HOWARD BRADY[2]
Bartlesville, Oklahoma

ABSTRACT

The Minnelusa formation of the northwestern Black Hills is divided into four lithological zones, and variations within the highest zone are noted. Four new fossil horizons are recorded, thereby establishing seven fossil horizons in the formation. Lists of fossils collected therein are recorded.

The fossils show that the Minnelusa formation of the Black Hills represents sedimentary deposits equivalent in age to parts of both the Upper and Lower Coal Measures series of the Mississippi Valley. The highest lithological zone yields fossils typical of the Missouri beds, and the lower three yield fossils typical of Des Moines beds.

During the summer of 1929 the writer studied the Minnelusa formation near Beulah, Wyoming, and made a collection of fossils from the upper part of the formation in South Redwater, Sundance, and Red canyons. He also studied the stratigraphy of the upper part of the formation and made correlations in the northwestern Black Hills region. The fossils collected prove that the age of the upper part of the formation is Pennsylvanian, and they determine correlation with beds of the Missouri division of the Pennsylvanian of the Mississippi Valley region. Heretofore the age of the upper beds has not been definitely known.

In the summer of 1929, geologists of the Kansas Geological Society, in their third annual field conference, were interested in the Minnelusa formation. The recent discovery of oil in the southern Black Hills arouses further interest. The writer believes, therefore, that this article is timely and hopes that it may serve as a contribution to the geology of the northern hills.

In Sand Creek Canyon south of Beulah, Wyoming, the Minnelusa formation may be divided into four lithological zones: (1) at the base a lower red and pink zone composed of red shale and red sandstone and of pink, cross-bedded sandstone, approximately 50 feet thick; (2) an intermediate zone of gray, irregularly thin-bedded and massive limestone

[1]Manuscript received, October 1, 1930.

[2]Indian Territory Illuminating Oil Company. Introduced by A. C. Trowbridge.

beds alternating with thin massive sandstone and thin shale beds, approximately 165 feet thick; (3) an upper red zone, predominantly massive sandstone, in which are a few layers of limestone and shale, approximately 91 feet thick; and (4) a top zone of yellowish saccharoidal calcareous sandstone, approximately 180 feet thick. This last zone is composed of four sandstone members alternating with limestone and siltstone. In places this zone is capped by residual chert or cherty limestone.

The following section of the Minnelusa formation was taken at the La Plant Ranch where Sand Creek crosses the east line of T. 52 N., R. 61 W.

Bed	*Description*	*Thickness in Feet*[1]	
	Opeche red shales		
49	Dense, arenaceous, buff, cherty limestone; fossiliferous horizon	22	
48	Yellow, calcareous, friable sandstone; differentially weathered; cavernous; poorly bedded. Lower part somewhat covered	72	
47	Buff sandstone; generally massive; where weathered, rough blister-like surface	24	
46	Pink, gray, and brown limestone, shale and siltstone; very arenaceous; poorly bedded; fossiliferous horizon	8	
45	Yellowish to reddish brown, coarse-grained sandstone	17	
44	Dense, arenaceous, gray and pink limestone and siltstone; fossiliferous horizon	5	
43	Buff to brown, calcareous and ferruginous sandstone; partly covered	30	
42	Lavender, granular, crystalline limestone	2	
41	Buff to red, massive, moderately cross-bedded sandstone; makes massive vertical walls	50	
40	White, gray, and purple calcareous shale	1	
39	Yellow to gray limestone; pink at surface; differentially weathered; contains many chert layers and nodules; fossiliferous horizon	5	11
38	White, gray, and purple shale	½–1	
37	Argillaceous gray limestone interbedded with thin layers of shale	4	
36	Light gray to pink, friable, calcareous, massive sandstone; forms vertical cliffs	30	
35	Buff limestone; pink at surface; a few thin beds of purple shale	1	
34	Buff, argillaceous limestone	9	
33	Thinly laminated, white, gray, and purple shale	½–1	12+
32	Buff limestone; somewhat argillaceous	2½	
31	Blue and purple shale	⅓	
30	White, hard, argillaceous limestone, irregularly bedded; differentially weathered at surface	8	
29	White, hard, calcareous shale	2	15+
28	Light gray, lithographic, brecciated limestone; irregularly bedded; differentially weathered; fossil fragments	5	
27	Gray, arenaceous, hard, massive limestone	4	
26	White, hard, calcareous, papery shale	1	23+
25	Gray, arenaceous thick-bedded limestone; brachiopod fragments	18	

[1]Numbers at right of brackets indicate thickness of corresponding units described in Figure 1.

Bed	*Description*	*Thickness in Feet*	
24	Pink, calcareous shale	½	30+
23	Buff, massive sandstone	2	
22	Calcareous, well bedded sandstone	2	
21	Buff, massive sandstone	3	
20	Pink, calcareous shale and sandstone	8	
19	White, calcareous, massive sandstone	5	
18	Brecciated, arenaceous limestone	2	
17	Buff, calcareous sandstone	8	
16	Buff, massive limestone; differentially weathered; plentiful nodules, and geodes filled with calcite crystals	20	
15	Thin-bedded, light pink sandstone	15	15+
14	Sandstone and clay conglomerates	¼	
13	Light cream-colored, dense crystalline bedded limestone; chert nodules; differentially weathered, fossiliferous horizon	20	
12	Gray shale	⅓	6+
11	Pink, very calcareous sandstone	5	
10	Limestone conglomerate with calcareous shale matrix	1	
9	Gray, crystalline limestone	4	9+
8	Red shale	⅔	
7	Light pink to gray arenaceous limestone; granular texture	4	
6	Red shale	½	
5	Pink, calcareous, massive sandstone	10	10+
4	Conglomerate and calcareous shale	½	
3	Pink, arenaceous, unevenly bedded limestone	5	
2	Pink, friable, cross-bedded sandstone; exposed at top of covered slope	50	
1	Red shale horizon	?	
	Pahasapa limestone		

Figure 1 is a graphic generalization of the foregoing section, showing the designated lithological zones, which are easily discernible in the northwestern Black Hills region. The only marked variations from this general uniformity are: (1) the absence in places of the thick, pink, cross-bedded sandstone at the base, (2) the absence of the cherty limestone at the top, and (3) the presence of local gypsum beds in the upper zone. The local gypsum beds are well developed in South Redwater, Sundance, and Red canyons, southwest of Beulah, Wyoming.

The stratigraphy of the upper zone of the Minnelusa in the northwestern Black Hills was learned in part by a study of the local gypsum beds. The members of the upper zone are present and discernible at most of the exposures studied. In Spearfish and Bear Butte canyons, east of Beulah, this zone has the same sequence and character of members as at the La Plant Ranch. In South Redwater, Sundance, and Red canyons, the members which compose the upper zone in the La Plant section are present but are interbedded with three successive sets of gypsum beds. In the outcrop at the east flank of the Bear Lodge Mountains uplift, the yellow sandstone members are present, though the fossiliferous limestone and siltstone members found farther east are absent.

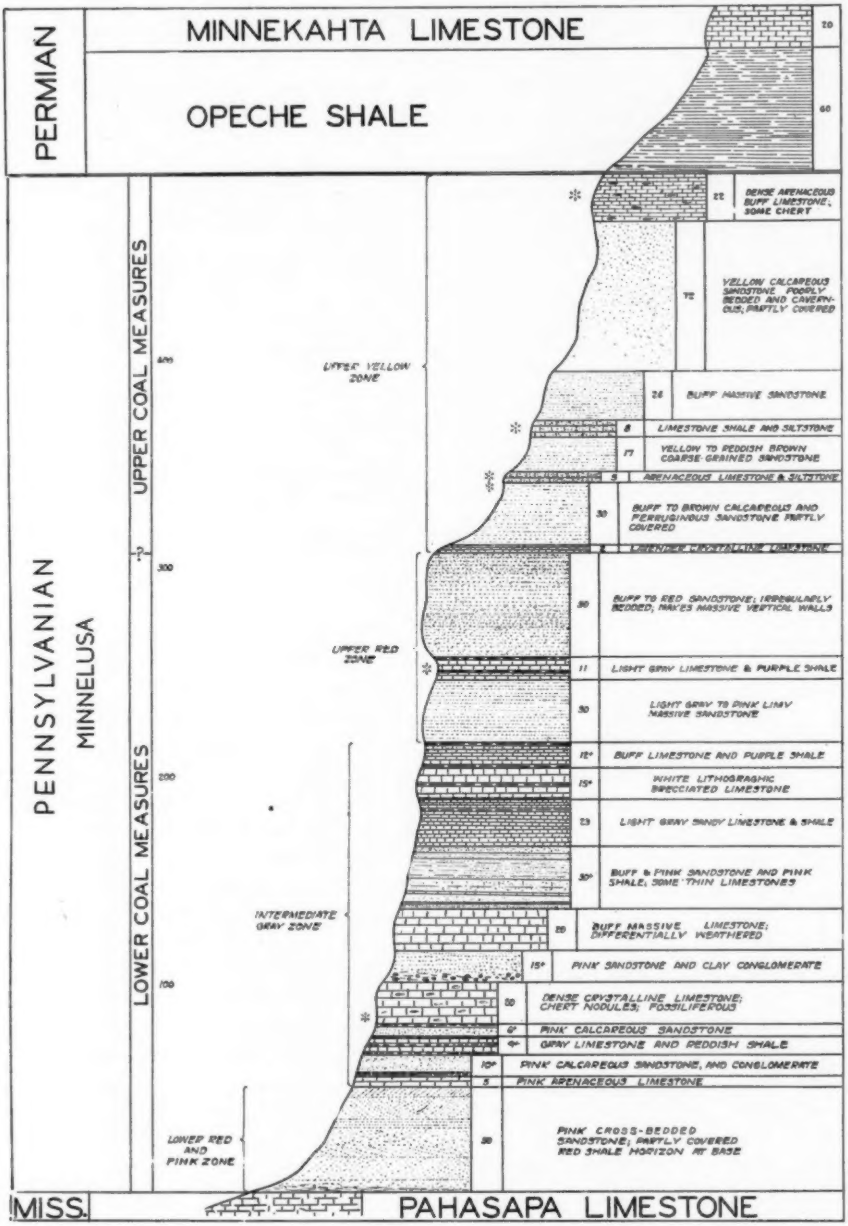


FIG. 1.—Generalized columnar section of Minnekahta, Opeche, and Minnelusa formations at La Plant Ranch in Sand Creek Canyon, south of Beulah, Wyoming, showing age, four lithological zones, and fossiliferous horizons (*) of Minnelusa formation of northwestern Black Hills.

Fossils were collected in South Redwater and Sundance canyons from beds 44, 46, and 49, and from a local limestone bed associated with the local gypsum but not present at the La Plant Ranch. The local limestone bed occurs between beds 43 and 44 in the gypsiferous localities. The following collections were made: (1) from bed 49, *Bulimorpha chrysalis, Loxonema ?* sp., crinoid stems and fragments of unidentified forms; (2) from bed 46, *Linoproductus cora, Productus* sp. of *P. cora, Pugnax osagensis, Hustedia mormoni, Ambocoelia planiconvexa, Derbya* aff., *crassa, Meekella* sp., *Nucula* sp., *Deltopecten occidentalis ?, Pseudomonotis equistriata, Macrodon* sp., *Murchisonia ?* sp., *Worthenia tabulata, Schizostoma catilloides, Bucanopsis* sp., undetermined gastropods and fish teeth; (3) from bed 44, *Lophophyllum* sp., *Linoproductus cora, P. semireticulatus, Marginifera* sp., *Deltopecten occidentalis,* and an undetermined gastropod; and (4) from the local bed associated with gypsum lenses, *Spirorbis carbonaris, Linoproductus cora* var., *Productus* sp. (several species), *Marginifera lasallensis, Pugnax osagensis, Hustedia mormoni, Ambocoelia planiconvexa, Edmondia nebrascensis, Nuculopsis anodontoides, Pinna peracuta, Squamularia perplexa ?, Deltopecten occidentalis, Pseudomonotis equistriata, Myalina kansasensis, Allorisma granosum* (or *gibbosa*), *Astartella ?* sp., *Pharkidonotus percarinatus, Strophostylus subovatus, Euphemus* sp., *Murchisonia* sp., *Pleurotomaria* sp., *Worthenia tabulata, Bellerophon* sp., *Bucanopsis* sp., *Schizostoma catilloides, Orthoceras* sp., *Tainoceras occidentalis,* undetermined cephalopods and fish teeth.

The four fossil-bearing horizons of the gypsiferous area were traced into the upper 150 feet of the fourth zone of the Minnelusa formation at the La Plant Ranch. The faunas collected from these horizons are typical of the Missouri beds of the Pennsylvanian of the Mississippi Valley, and indicate that the upper zone of the formation in the northwestern Black Hills is Upper Coal Measures in age. The local beds of the gypsiferous area, which lie between beds 43 and 44, and beds 44, 45, and 46 as numbered in the La Plant Ranch section, are probably Kansas City in age; those above are probably of later Pennsylvanian age. The lowest of these fossiliferous horizons is as much as 100 feet above the highest horizon established by Glenn S. Dillé in his article on the "Minnelusa of Black Hills of South Dakota."[1]

The three fossiliferous horizons established by Dillé in the lower part of the Minnelusa occur also in the La Plant Ranch section in Sand Creek Canyon. The basal red shale bed is thin and not fossiliferous.

[1] *Bull. Amer. Assoc. Petrol. Geol.,* Vol. 14, No. 5 (May, 1930), pp. 619-23.

The following forms were obtained from Dillé's second horizon, which is 80 feet above the base of the formation: *Lophophyllum* sp., *Chaetetes milleporaceous*, *Composita subtilita* (plentiful), and *Phillipsia* sp., indicating that these beds are Cherokee in age. The third horizon established by Dillé is 250 feet above the base of the formation at this place. It bears fragments of brachiopods, among which *Productus* and *Chonetes* were recognized. The age of this horizon has not been determined.

The three fossiliferous horizons established by Dillé and the four recorded in this article comprise seven fossiliferous horizons in the Minnelusa formation of the Black Hills, six of which contain fossils in the northwestern hills in the Beulah region. The paleontological evidence in this article concerning the upper beds of the Minnelusa and the evidence given by Dillé concerning the basal beds strongly indicate that sediments equivalent to parts of the Des Moines and to parts of the Missouri series of the Mississippi Valley are present in the Black Hills.

The contact between the upper and the lower series has not been established. Inasmuch as Upper Coal Measures fossils occur in the four upper horizons and inasmuch as Lower Coal Measures fossils occur in the lower horizons, the contact between the Upper and Lower Coal Measures will probably be found somewhere between Dillé's third horizon and the lower horizon mentioned in this article. Discovery of more fossils between these horizons should aid in determining more closely the contact between the Upper and Lower Coal Measures in the region.

The fossils collected are in the repository at the State University of Iowa, in charge of A. O. Thomas, who assisted the writer in their identification. Dr. Thomas has also read and criticized this manuscript; J. J. Runner has aided in the field problems.

CAN ABSENCE OF EDGE-WATER ENCROACHMENT IN CERTAIN OIL FIELDS BE ASCRIBED TO CAPILLARITY?[1]

J. VERSLUYS[2]
The Hague, Holland

ABSTRACT

In several oil fields the amount of edge water invading the wells after the field is almost exhausted is very small. This may be due to different causes, some of which are briefly mentioned in this paper. The writer's object is to show that capillarity can not hold the oil outside the depleted area around the well and can not prevent the edge water from moving toward the well.

In the depletion zone two conditions are possible when the formation is an unconsolidated sand, (1) the funicular and (2) the pendular. In the former, oil and generally gas flow freely. In the latter, gas flows freely and may be followed by oil.

If the oil-bearing formation is consolidated and the interstices are pores with narrowings, Jamin effect would not stop the flow altogether because the gas would diffuse through the films of oil which shut off the pores in the narrowings. Light oils would evaporate from one film and condense on the next nearer to the well and thus move toward the well.

It can be proved, however, that if a certain number of gas bubbles could stop the flow of oil, the number of bubbles necessary to fulfill this condition would not be formed, so that oil would move toward the well, ultimately followed by edge water, unless it is held back by other causes.

In some oil fields edge water encroaches so slowly that it is negligible and almost imperceptible. There are many such fields in the Bartlesville sand in the Mid-Continent area, and a few in the Dutch East Indies.

It would be incorrect to say that formations containing no edge water exist. Oil-bearing formations are generally of marine origin. From the beginning the voids were filled with water. Only in smaller parts, most of which are structurally high, may oil and gas have accumulated. The present oil-bearing layers were buried either under the ocean or on the continent—although in the latter situation, which is less common, the strata were saturated with water, for the phreatic surface (water-table) is in few places deeper than some tens of feet below the surface of the ground.[3] In sand dunes this depth may be greater, but when the strata are being covered with younger sediments they are either under the ocean or beneath the phreatic surface, and the inter-

[1]Manuscript received, November 20, 1930.

[2]Bataafsche Petroleum Maatschappij, 394 Frankenslag.

[3]J. Versluys, *Capillarity in Soils* (Amsterdam, 1916). In Dutch.

stices are filled with water. Therefore, all voids in the layers, under the continent and under the ocean, are filled with water unless this has been replaced by oil or gas.

The pressure head of water and of other fluids (oil and gas) in the earth's crust differs little from the pressure exerted by a column of water of a height equal to the depth of the point considered. So far as the writer knows, J. H. Gardner,[1] in 1917, was the first to give proper attention to this law regarding oil and gas. In high areas, water from precipitation penetrates and percolates downward; in low areas, water rises, and is drained by rivers. Consequently, in low areas, as a rule, the pressure of the fluids is somewhat greater than the so-called hydrostatic pressure, and the pressure head generally increases with depth.[2] In higher districts, as a rule, the reverse occurs. At any depth the fluids in the pores of the rocks have a pressure head which differs little from the hydrostatic pressure of this depth. K. Krejci[3] contends that this rule does not exist and refers to one of M. J. Munn's papers. Munn[4] merely stated that there are differences in the initial closed pressures of gas wells in a specified area. These differences, however, can be ascribed to the interference of other producing wells and to exhaustion of the field. A. A. G. Schieferdecker brought to the writer's attention some deviations of this law as applied to gas layers in Roumania. It seemed that the observed pressure in the gas layer corresponded with the hydrostatic pressure at the depth of the contact of gas and liquid in the sand. Therefore, instead of doubting Gardner's principle, Schieferdecker and the writer are inclined to believe that the depth of the contact of gas and liquid can be approximately estimated from the pressure of the gas in a gas sand or gas cap of an oil sand in a steep structure.

Although all the voids of the strata which do not contain oil or gas are filled with water, in many fields, as already stated, a sand, after producing oil for some time, becomes exhausted without yielding an appreciable amount of water.

[1] "The Mid-Continent Oil Fields," *Bull. Geol. Soc. Amer.*, Vol. 28 (1917), pp. 700-02.
Also J. Versluys, "Synclinal Oil and Unsaturated Strata," *Proc. Royal Acad. Sci.*, Vol. 31 (Amsterdam, 1928), pp. 1086-90.

[2] J. Versluys, "The Origin of Artesian Pressure," *Proc. Royal Acad. Sci.*, Vol. 32 (1930), pp. 214-22.

[3] *Grundfragen der Ölgeologie* (Stuttgart, 1930), p. 79.

[4] "The Compton Oil Pool, Kentucky," *U. S. Geol. Survey Bull. 471* (1910), p. 15.

The first stage of production of an oil well, generally termed the period of flush production, corresponds approximately with a phenomenon at depth which can be termed depletion. Before production, the oil contains dissolved gas. When production begins, part of this gas is liberated near the well; the part of the oil forced into the well is replaced by gas; and part of the gas flows out. This process of the oil being expelled from the pores by gas originating from this oil and taking its place in the pores, may be termed "production by depletion," to distinguish it from the production due to the propelling of oil by edge water or the gas from a gas cap. The daily production of a well which is due to the depletion process continually decreases. The part of the formation in which the pores are partly filled with gas extends in wider and wider zones around the well. The distance from the well where pressure has declined increases during this stage, which ends as soon as the volume of oil, propelled to the well by the pressure of the edge water per unit of time, counterbalances the production of the well. Then the oil flows as a liquid with dissolved gas to the border of the depletion zone, where pressure has so declined that liberation of gas occurs. In the depletion zone there is a flow of oil with partly dissolved and partly free gas. If further details of the process be disregarded, namely, the complication caused by other wells and irregularities in the texture of the formation and the dip of the strata, the oil finally becomes exhausted and edge water reaches the well.

How can the absence of edge water in some fields be explained? If faults have divided a field into isolated blocks so that some parts really contain no edge water, production would be only a consequence of depletion, as already described, and finally of gravity within the isolated blocks. If the down-dip part of an isolated block contains water, and if oil is produced from wells in the structurally higher parts of the block, the water will not be predisposed to flow toward the well. It probably contains gas, and the forces which cause depletion of the oil zone will also act in the water, but because gas is less soluble in water than in oil, this process will have little effect on the water. Furthermore, the water in an isolated block could be propelled and recharged only by other water, which, however, could be supplied only by percolation through the less pervious overlying and underlying rocks; this means that it would flow very slowly.

Cementation of the sand may have an effect similar to that produced by faults.

Oil and gas accumulate in the coarser strata, and if these strata are not homogeneous, oil and gas will tend to accumulate in the coarser parts. This can be explained as follows. The minerals which constitute the strata are generally wetted more easily by water than by oil, although both liquids tend to wet a dry surface, replacing gas. The energy per unit of area of surface of a mineral grain is greater for contact with gas than with oil, and this energy is greater for oil than for water. Therefore, the molecular energy becomes less when oil replaces gas, and when water replaces either oil or gas. Consequently, if only the two liquids are present, water and oil tend to shift so that the greatest area of the surface of mineral matter is wetted with water. This condition is fulfilled if water occupies the narrowest pores, a unit of volume of liquid having a greater area of contact with solid matter, as the pores are narrower. When gas, oil, and water are present, gas tends to occupy the coarsest parts, water the finest. Because of these phenomena the finer strata are generally filled with water and oil, and gas can not easily migrate from one coarse layer to another. Black shales, which in many places contain gas, are excepted, because they may contain solid organic matter, the behavior of which toward water is different from that of mineral matter.

Therefore, it is possible that oil has accumulated mainly in the coarser parts of a sand. Hence, when the production due to the depletion process is finished, it will be followed by a very slow, sometimes negligible encroachment of edge water. The motion of the edge water is very slow because the fineness of the pores outside the oil offers great resistance.

The compaction of the sands may continue after accumulation of oil and gas in either the coarser or the structurally higher parts of the layers. Only at very great depths can such compaction in sand layers be a consequence of the crushing of grains because of the pressure of superincumbent strata.[1] At less depths, however, the compacting pressure may cause dissolution of mineral grains in some parts and deposition in the vicinity. Part of the liquid is squeezed out. The pore space becomes smaller; the sand becomes cemented and may separate the originally continuous pores into minute isolated compartments. This cementing process can not occur in oil- or gas-filled parts, because the minerals are not soluble in oil or gas. Thus, if before the accu-

[1] C. R. Van Hise and L. M. Hoskins, in 1894-95 (*U. S. Geol. Survey 16th Ann. Rept.*, Pt. I), estimated this depth at approximately 6 miles.

mulation of the oil the pore space was the same throughout the sand, this may afterward decrease outside the oil because of compaction.

The writer's object in this paper is not to expatiate on the phenomena of compaction and cementation, and faults. These subjects are merely mentioned in order to show that various causes may result in a very slow encroachment of edge water.

Herold gave proper attention to the absence of edge water in certain oil reservoirs which he termed "reservoirs of the closed type."[1] Distinction was made between "sealed lenses" and "reservoirs under capillary control," both being reservoirs of the closed type.[2] Herold suggested a method of determining from the diagram of time and rate of production whether or not the reservoir belonged to the closed type. The writer agrees with him that oil reservoirs which show no invasion of edge water should be distinguished from other reservoirs and that a term like "closed type" is needed. The writer, however, doubts whether capillarity has much to do with the phenomenon.

In 1916 the writer's thesis on the capillarity in soils was published in the Dutch language,[3] and soon afterward an extract of it was published in German.[4] In this thesis he proved that in broken solids, like soils and sands, three conditions of saturation with liquid may be distinguished, namely, (1) complete saturation, (2) funicular condition, and (3) pendular condition.

Both funicular and pendular conditions are controlled by capillarity. Pendular condition exists when there are small bodies of liquid (pendular bodies) at the points where the solid constituent of the broken mass (the grains of a sand) are in contact with one another. A cross section of pendular bodies is shown in Figure 1 for the ideal condition of globular grains.

Figure 2 is a cross section of an ideal broken solid where a funicular condition prevails. This results from the pendular condition when the liquid bodies expand. There is a continuous network of liquid, and cirulation of the liquid may occur. This explains how water from the surface of the earth may percolate to the phreatic ground-water, without saturating the upper part of the soil. Liquid in this condition has a

[1]S. C. Herold, "Mechanics of a California Production Curve," *Petroleum Development and Technology, 1930* (Amer. Inst. Min. Met. Eng.), pp. 279-90.

[2]*Op. cit.*, p. 281.

[3]*De capillaire werkingen in den bodem* (Amsterdam, 1916).

[4]Die Kapillarität im Boden," *Internationale Mitteilungen für Bodenkunde* (1917), pp. 117-40.

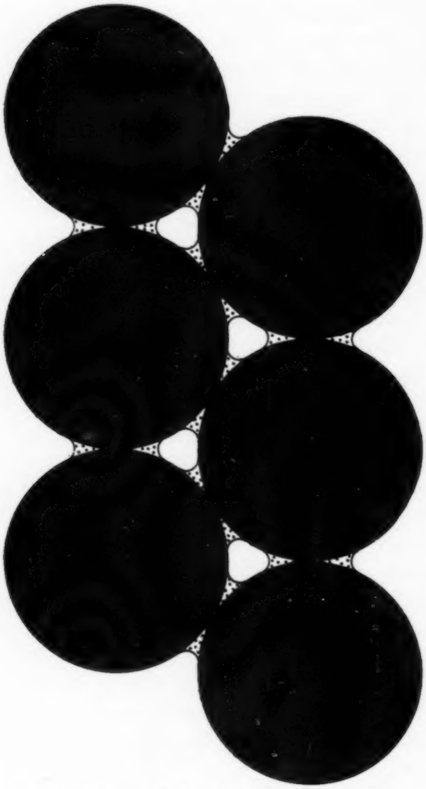


FIG. 1.—Cross section of pendular bodies showing ideal condition of globular grains.

tendency to sink because of gravity, but it has also a tendency to flow in a homogeneous, broken solid from a place where the degree of saturation is greater to places where it is less. It also tends to flow from places where the gas which fills the parts of the pores left free by the liquid has a greater pressure to places where this pressure is lower.

The gas in a broken solid in which funicular conditions prevail may or may not be continuous. The funicular liquid may leave an open space in the pores which forms a gas-filled network throughout the mass, but it may also shut off the narrower parts of the pores, dividing the gas into isolated bubbles.

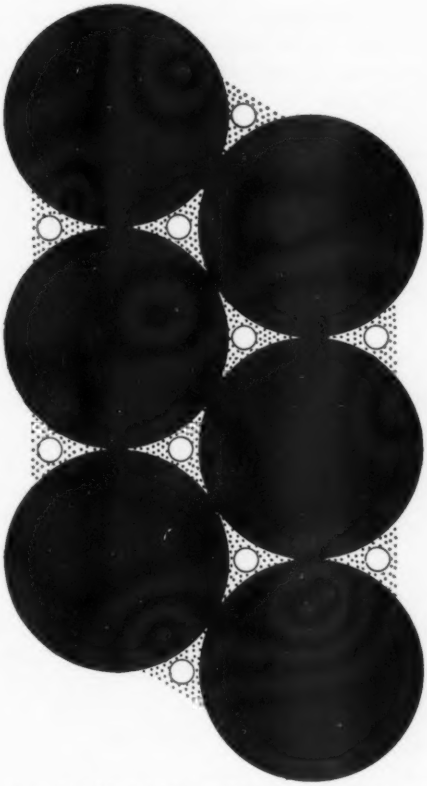


FIG. 2.—Cross section of an ideal broken solid where a funicular condition prevails

As long as the oil in a broken solid contains no free gas, the broken solid is saturated, and oil may flow according to the laws of Poiseuille and Darcy.[1] As the motion is slow, kinetic energy is small so that the motion is only counteracted by internal friction of liquid and gas. Consequently, these laws control the motion, and Torricelli's law does not interfere.

[1] J. Versluys, "The Equation of Flow of Oil and Gas to a Well After Dynamic Equilibrium Has Been Established," *Proc. Royal Acad. Sci.*, Vol. 33 (Amsterdam, 1930), pp. 578-86.

Voruntersuchung und Berechnung der Grundwasserfassungsanlagen (Munich-Berlin, 1921).

If there is free gas, either the funicular or the pendular condition may prevail. While there is much liquid, the former condition exists, and the liquid flows, because of gravity, pressure differentials, and capillary forces, which are not elaborated in this paper. Free gas also may or may not flow in this condition, depending on the rate of saturation. The less the saturation with oil, the more freely the gas may move.

When the oil is drained, the pendular condition gradually occurs, in which no more oil can flow, but in which the gas is very little hampered by the liquid. Consequently, in a real sand either the gas or the liquid, or both, can move without interference.

In the pendular condition, which may occur only after most of the oil has been drained, it has been stated that oil can not flow. But if oil is continuously added somewhere, the pendular bodies grow, the pendular condition is converted into the funicular, and oil flows. Consequently, as long as there are differences of pressure in the gas or differences of pressure head in the oil in a true sand, oil and gas move, in spite of capillary forces, unless the pendular condition prevails.

In many places, however, the so-called oil sands are consolidated rocks. It can not be assumed that laws which are derived from molecular forces for broken solids apply to hardened sands.

Herold[1] used the Jamin effect to explain the absence of encroachment of edge water. In 1860 J. Jamin[2] published the results of his experiments on capillarity in glass tubes. He observed a considerable difference of pressure maintained for a long time in a capillary glass tube of uniform width, filled with many alternating small bodies of water and air. With this experiment, however, not all precautions were taken. The tube was filled by suction at one end, while a finger wrapped with a moist white linen cloth was alternately pressed on the free end of the tube and withdrawn. Jamin concluded from his experiments that in a narrow tube a number of gas bubbles are able to cause a considerable resistance to the flow of the liquid for a long time. Thirteen years later J. Plateau[3] proved that Jamin had not taken all the necessary precautions with his experiments. With the precautions Plateau took, the effect

[1] "Jamin Action—What It Is and How It Affects Production of Oil and Gas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 6 (June, 1928), pp. 659-70.

[2] "Mémoire sur l'équilibre et le mouvement des liquides dans les corps poreux," *Comptes Rendus*, Vol. 50 (1860), pp. 172-76.

[3] *Statique expérimentale et théorique des liquides soumis aux seules forces moléculaires*, Vol. 2 (Paris, 1873), pp. 80-82.

See also: I. I. Gardescu, "Behavior of Gas Bubbles in Capillary Spaces," *Petroleum Development and Technology, 1930* (Amer. Inst. Min. Met. Eng.), pp. 351-68.

was much less. The writer believes that the Jamin effect would not be observed in a cylindrical tube, if it were possible to work more accurately than Plateau did. For example, if the liquid wets the entire surface of the tube, according to theory, the Jamin effect should be rejected altogether in connection with a cylindrical tube. Suppose a straight cylindrical tube is entirely wetted with a liquid and in the tube is a bubble of gas, as shown in Figure 3. If the liquid with the enclosed bubble is moved from right to left, so that the bubble is first at *A*, and afterward at *B*, in both places the bubble has the same shape and area. Consequently, the area of the interface of liquid and gas has not changed. Neither has the area of the interface of liquid and solid (the area of the inner surface of the tube) increased or decreased. This means that the energy of the molecular forces is not changed as the liquid and the gas bubble are submitted to a virtual displacement. Thus, in a wetted tube the gas bubble would not cause a resistance to the motion of the liquid because of molecular forces or capillarity. This is true for more than one bubble.

FIG. 3.—Cylindrical tube entirely wetted with a liquid, showing similar form of bubble of gas at *A* and at *B*.

However, if there are contractions in the cross section of a tube, the Jamin effect certainly exists theoretically. In each contraction a body of liquid would cause a resistance to the passage of gas. But would this stop the flow altogether?

If there are two equal and similarly shaped narrowings in a tube, if at these narrowings the space is obstructed by a body of liquid, and if pressure is higher on the right side than on the left, the bodies of liquid are placed in such a position that in both narrowings the curvature on the right side is greater (radius of curvature smaller) than on the left side. This means that an equilibrium between free and absorbed gas could exist only if pressure were lower on the right side than on the left side, whereas the contrary is the fact. Consequently, gas must continuously diffuse through the body of liquid from right to left, which in a well in an oil layer means that gas must move toward the well, partly because of diffusion through the oil bodies.

The gas in the space between the narrowings is saturated with vapor of the liquid; pressure may be assumed to be the same throughout this space. If the narrowings have the same shape and the bodies of liquid the same volume (Fig. 4), the curvature at *B* is less than at *C;* consequently, liquid evaporates from the right body of liquid at *B* and condenses on the other body at *C*. What is the effect of this phenomenon

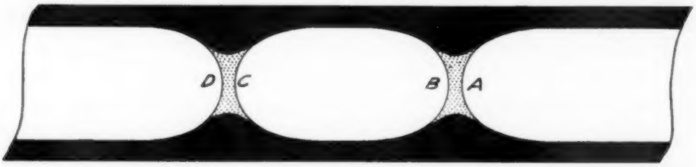


FIG. 4.—Diagram of vapor-saturated tube, in which narrowings have the same shape and bodies of liquid the same volume.

in the oil-bearing sand? If all the narrowings had the same shape and size, the oil would evaporate from the high pressure to the low, from one body to another; that is, it would move toward the well. If the narrowings are not equally large, oil gradually evaporates from the wider and condenses at the narrower, until a constant flow of vapor and gas toward the well has started.

In the foregoing paragraphs, two phenomena of diffusion toward the well have been treated, namely, of gas and of oil.

If the conditions, as assumed by Herold for his capillary control, do exist, the diffusion of gas would cause the gas bubbles at the border of the depletion zone (farthest from the well) to disappear. After this, the next farthest gas bubble would disappear, this process would continue, and capillarity would not stop the flow of gas and oil toward the well. The question of motion of oil toward the well by diffusion would not be very effective except with light oils. However, because the diffusion of gas occurs with heavy oils also, narrowings in the pores can not stop the flow.

The question of diffusion, however, is not of most importance, as it can be proved that gas bubbles would never be formed in sufficient number to stop the flow of oil due to the pressure of edge water. In loose grains, as already explained, the funicular condition would occur, and gas and oil would flow. In pores with contractions in a consolidated sand, Jamin effect would cause resistance, provided the conditions of the

tube of Jamin exist. But, in the writer's opinion, this is erroneous. In the oil reservoir the conditions are different. In Jamin's experiment the air and water were introduced separately, and at the pressures prevailing during the experiment the air would not be entirely absorbed by water.

In an oil-bearing formation there is oil with dissolved gas. Due to the decrease of pressure in the well, gas is liberated from the oil and bubbles of gas are occluded by the oil. If this should occur up to point *A* in Figure 5, according to Herold's theory these bubbles would obstruct the passage. At any point at a greater distance than *A* from the well, there would be no motion, nothing would change, and the pressure

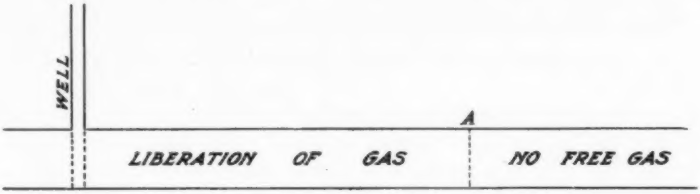


FIG. 5.—Diagram showing liberation of gas next a well, continuing to a theoretical limit (*A*) beyond which the original pressure prevails.

would remain the same; that is, at any place farther away from the well than *A*, the original pressure would prevail. This means that the remotest bubbles (those near *A*) would be surrounded by oil from which the gas which formed these bubbles has been liberated, but this oil would have the original pressure, and at this pressure the bubble could be dissolved in the oil. As a consequence, the gas bubble will be re-absorbed by the oil. Two results are possible. If the resistance of the remaining bubbles is not sufficient to stop the flow, the motion continues. If the remaining bubbles, however, offer sufficient resistance to oppose the motion of the oil, the next remotest bubble is absorbed for the same reason the first has already been absorbed, and so on. However, the bubbles supposed to have been formed and afterward absorbed would not come into existence, so that the formation of gas bubbles in the oil in wider and wider zones about the well is terminated before these bubbles could exert the Jamin effect to an extent sufficient to counterbalance the pressure of the edge water.

The writer concludes that capillary control of oil fields does not exist. It is probable that the fields supposed to have capillary control

are fields where, because of faults or tightness of the formation outside the oil accumulation, there is great resistance to the motion of the edge water. The writer agrees with Herold that, from the standpoint of the production man, oil accumulations in true, uninterrupted sheet sands can be distinguished from oil accumulations in lenses, lenticular coarser parts of tight sheet sands, and isolated blocks enclosed by faults. The classification of reservoirs with capillary control, however, should be dropped.

The question of diffusion and absorption of gas bubbles in a liquid is treated in a recent paper by H. Mache.[1] This paper is also a key to literature on this subject and similar subjects.

In addition to the foregoing, it should be remembered that encroachment of edge water may occur in strata which have no outcrops.[2]

[1]*Akademie der Wissenschaften in Wien Sitzungsberichte*, Abt. IIa, Vol. 138 (1929), pp. 529-56.

[2]J. Versluys, "The Origin of Artesian Pressure," *Proc. Royal Acad. Sci.*, Vol. 32 (1930), pp. 214-22.

GEOLOGICAL NOTES

NEW PRODUCTIVE HORIZON IN CALIFORNIA

When the Dudley Ridge Oil Company's well blew in on May 19, 1929, from below the casing shoe at 1,125 feet, it definitely proved a new horizon as a source of gas and possibly of oil in California. This well is located in Sec. 12, T. 23 S., R. 19 E., near the west shore line of the dry bed of Tulare Lake, Kings County, California.

The rocks expelled and scattered by the 475-pound gas pressure are chiefly of organic nature, fine-grained, gray, brittle, and of the same leafy or fissile structure as the oil shales of some Rocky Mountain districts. They yield no appreciable extract with solvents, but when heated in a flame they almost burn and in a closed tube they yield petroleum. G. D. Hanna, of the California Academy of Sciences, examined material from a third well drilled into this shale stratum and described it as containing many fish bones and smooth kidney-shaped ostracods. A few diatoms were present, among which he recognized *Stephanodiscus* and *Melosaria*.

The formation in which this oil shale occurs is the Tulare of Pliocene age and of fresh- to brackish-water origin. It has a thickness of 3,200 feet. Cores from subsequent wells in the vicinity have shown that the Tulare formation is composed mostly of grayish to bluish shales, and that it is fairly rich in diatoms. Associated sands contain brackish to saline water except near the surface, where some fresh water is found. Other wells in the vicinity have had oil showings associated with gas at shallow depths.

Heretofore the Tulare formation has not been seriously considered as a possible primary source of commercial oil or gas. Further study of this occurrence will probably contribute more information on the subject of the origin of oil and gas.

WALTER STALDER

SAN FRANCISCO, CALIFORNIA
December 27, 1930

RECENT SUBSIDENCE IN HAMILTON COUNTY, KANSAS

During the last field conference in Colorado and New Mexico, sponsored by the Kansas Geological Society, W. L. Stryker, W. A. Ver

Wiebe, and the writer visited the locality of a recent sink hole 15 miles directly south of Coolidge, Kansas, which is in Hamilton County a few miles east of the Kansas-Colorado boundary. Figure 1 is a view of the sink hole as it appeared on August 29, 1930. It is near the north rim of a

FIG. 1.—Coolidge sink hole in Hamilton County, Kansas. Public road shows in left part of view; dark bands at *A* and *B* show locations of crevices partly encircling pit.

broad, generally basin-shaped valley. It was estimated that the pit is approximately 100 feet wide and 40-50 feet deep; the ground plan is almost circular. The walls are undercut, the sod and soil forming an overhanging lip, which gives the pit somewhat the appearance of a large cistern. The floor of the pit has the shape of an inverted cone with low-angle slopes; a shallow pool of water covered a small part of the floor. The material exposed in the walls and bottom of the pit is fine homogeneous silt; no stratified rocks were seen. Three sets of crevices encircle the sink hole, the farthest being 45 feet from the edge; two of these are shown in Figure 1 outlined by the dark bands of vegetation. The grass is greener and more abundant on the edges of the crevices than in the intervening spaces.

The sink hole is reported by H. L. Willoughby[1] to have broken through the surface on December 18, 1929. It has enlarged somewhat since its appearance. Willoughby reports the pit to have been 60 feet wide and approximately 40 feet deep on July 1, 1930; and 104 feet wide and 68 feet deep on August 8, 1930.

Sink holes are common in regions underlain by thick beds of limestone, where the surface water percolating downward through the rock dissolves and removes the easily soluble calcium carbonate, thus forming an underground cavern. Eventually enlargement of the cavern by the

[1]H. L. Willoughby, *The Kansas City Star* (August 9, 1930).

STRATIGRAPHIC SECTION[1]

Age	*Formation and Member*	*Lithologic Character*	*Thickness (Feet)*
Recent		Alluvium	0–50
Pliocene and late Miocene	Ogalalla formation	Sand, clay, gravel and "mortar beds"	0–150
	—Unconformity—		
Upper Cretaceous	Carlile shale Blue Hill shale member	Not exposed near the sink hole	100
	Fairport chalky shale member	Calcareous shale with thin-bedded chalky limestone near base	147
	Greenhorn limestone Bridge Creek limestone member	Alternating calcareous shale (4/5) and thin beds of chalky limestone (1/5)	74
	Hartland shale member	Calcareous shale	23
	Lincoln limestone member	Calcareous shale; thin-bedded finely banded limestone; and thin chalky limestone (9/10, calcareous shale; 1/10, limestone)	35
	Graneros shale	Gray-black fissile clay shale, with thin-bedded limestone 22 feet above base	61
Lower Cretaceous (?)	Dakota sandstone and possible representative of Lower Cretaceous Purgatoire formation and Lower Cretaceous (?) Morrison formation	Irregularly bedded light-colored fine-grained sandstone, sandy shale, and shale in upper part; dark shales near middle; and light tan sandstone at base	400+
	—Unconformity—		
Permian (?)		Soft red rock	193
		Gray limestone (possibly anhydrite) with 8 feet red rock break	26
		Red rock, in parts sandy	124
		"Lime" (probably anhydrite)	12
		Red rock, sandy	8
		Limestone and shale	15
		Red rock, in part red sand	146
		Pink limestone	29
		Sandy red rock	95
		Chalky limestone	18
		Green shale	7
		Red sandy shale	15
		Red sandy shale and salt	20
		Salt	18
		Salt and red shale	46
		Red shale with small amount of salt	58
		Red shale and sand	300
		Salt	35
		Limestone	21
		Chiefly red rock	300

[1]In part from N. W. Bass, "Oil and Gas Possibilities in Western Kansas," *Kansas Geol. Survey Bull. 11*. Description of section below upper part of Dakota sandstone is taken from driller's log of Wood Oil Company's Ransom No. 1, drilled in NW. cor., Sec. 5, T. 26 S., R. 41 W., Hamilton County.

continuation of the process weakens the roof, which fails and permits the overburden to drop into the cavern. The sink hole is the result. The absence of thick beds of limestone near the surface make the Coolidge sink hole seem at first somewhat exceptional.

Although no bed rock is exposed in the walls of the sink hole, beds of chalky limestone and calcareous shale belonging in the Fairport chalky shale member of the Carlile shale of Upper Cretaceous age are exposed in the road bordering it on the east and in the hillside a few hundred feet north of the sink hole. The beds exposed in the road 15-200 feet northeast of the sink hole dip toward the pit at angles as great as 5°. The age of the exposed rock was recognized by the lithology and by fragments of fossils which were identified in the field by J. B. Reeside, Jr., of the U. S. Geological Survey, as *Inoceramus fragilis*, a Carlile species.

As shown in the table of formations, the Greenhorn limestone underlying the Fairport chalky shale member, therefore underlying the surface in this locality, consists of 132 feet of chalky limestone and calcareous shale. The shale comprises four-fifths or more of the formation. The shale contains a large amount of calcium carbonate, which, however, could be removed easily by solution, together with the limestone beds. The Graneros shale immediately below the Greenhorn limestone is composed of relatively impervious clay shale. Other easily soluble rocks occur several hundred feet below the Greenhorn limestone, according to the record of the well drilled in Sec. 5, T. 26 S., R. 41 W., approximately 10 miles east of the sink hole. However, it is believed plausible to conclude that the cavern whose roof failed was formed in the Greenhorn limestone. As this formation is chiefly, if not entirely, above the level of the water table, and contains a large amount of calcium carbonate, it offers satisfactory conditions for the removal of much material in solution. The deep fill of silt shown in the pit walls and the steep dip (5°) of the Fairport limestone beds toward the pit indicate that the present pit may mark the locality of former sink holes perhaps of greater dimensions than this one.

The luxuriance and greenness of the grass bordering the crevices encircling the sink hole are caused by deeper wetting of the soil there than in the intervening spaces covered by an unbroken sod. Much water from showers is lost by surface run-off from the unbroken sod spaces and is received by the crevices, wetting the soil and subsoil to a depth of several feet.

It is to be expected (1) that ground settlement about the pit will continue and will gradually widen the crevices encircling the sink hole;

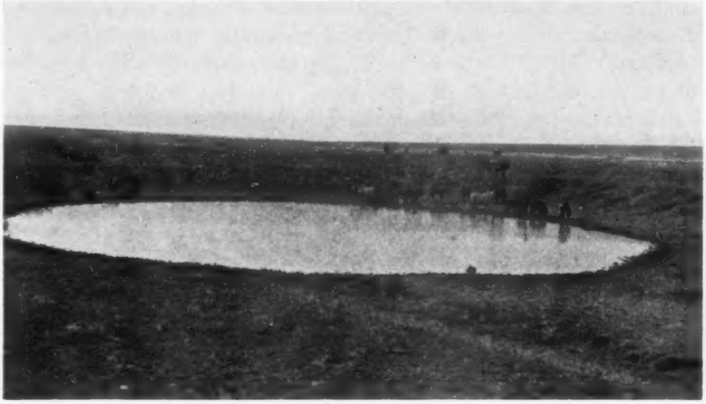


FIG. 2.—Basin in Sec. 25, T. 25 S., R. 43 W., Hamilton County, Kansas. After N. W. Bass, "Oil and Gas Possibilities in Western Kansas," *Kansas Geological Survey Bull. 11.*

(2) that the material nearest the sink hole will move inward most rapidly and slough off into the pit, partly filling it; (3) that other crevices will form; and (4) that the creep toward the pit will continue until it becomes merely a saucer-shaped basin.[1] Figure 2 is a view of what is believed to have been a sink hole that has been filled to its present state chiefly by the process outlined.

N. W. BASS

WICHITA, KANSAS
January, 1931

DISCOVERY OF OIL IN WHITE POINT GAS FIELD, SAN PATRICIO COUNTY, TEXAS, AND HISTORY OF FIELD

Hydrogen sulphide in gas seeping from a spring or water-hole at the west side of the White Point peninsula led to the exploration for oil, according to the theory that a salt dome might be present.

Disseminated grains of sulphur are found in outcropping sandy sediments on the west side of the peninsula. Subsequent drilling, of

[1]The sink hole was seen again October 25, 1930; it was almost brim-full of water; the sides had sloughed off into the pit, widening it to a diameter of 130 feet.

sixty-six wells, has not disclosed salt-dome structure or materials. Geophysical exploration in the field is stated not to have shown the presence of a salt dome or salt ridge.

The first well in the field was drilled about 1907 by Randolph Robertson, and blew gas for several days from its total depth of 400 or 450 feet. Shortly afterward Lee Hager and others drilled to 1,200 feet and also found gas.

Between 1913 and 1926, approximately thirty wells were drilled for oil without success. Local interests, including the White Point Oil and Gas Company, drilled several wells. The Guffey interests, later Gulf Production Company, drilled seven wells. One of these Gulf wells was later salvaged by the White Point Oil and Gas Company, which sold almost 1,000,000,000 cubic feet of natural gas to the town of Taft. During this period there were several spectacular gas blow-outs. Two large, deep craters remain on the peninsula as evidence. This drilling demonstrated the occurrence of gas in large volume, with high pressure. Some of these wild wells blew for months, and one blew for 2 or 3 years. Several gas sands were found, the deepest at 3,840-3,880 feet. Two wells had showings of oil, one above 1,025 feet and the other above 2,260 feet. Another well, probably the Gulf Production Company's No. 3, White Point Development Fee, showed gasoline. Although the records of two wells drilled during this period seem to show pressures greater than hydrostatic, in one well there were sands in the open hole deeper than in the hole from which the gas was supposed to be coming, and in the other there is no record of the gauge having been tested after years of use.

Beginning about 1922, the Moody-Seagraves organization acquired leases and drilled four wells, the deepest to approximately 4,100 feet. Two of these wells showed oil, and at least two showed gas. At that time no market existed for the gas. Little was then known about the possibilities of producing gas from semi-consolidated sand. However, during this period, W. L. Pearson, of Houston, and associates had completed two gas wells in the Saxet field on the south shore of Nueces Bay and were selling gas to the city of Corpus Christi.

In 1927, encouraged by the production of gas in the Saxet field and by the completion of gas wells at Refugio and Edna, the Moody-Seagraves group and the Houston Oil Company were completing their plans for piping gas to Houston. W. L. Pearson and S. R. Merrill, of Houston, acquired leases at White Point and agreed to operate these and the holdings of the Houston Gulf Gas Company for the Moody-Seagraves interests and to develop a daily production of 25,000,000 cubic feet by

January 1, 1928. The writer was engaged to assist in the development of the gas in the two fields on Nueces Bay for the Saxet and Nueces companies, which were later consolidated by Pearson by the formation of the Saxet Gas Company and the Saxet Oil Company. Leases at the north end of the field were developed by the Houston Oil Company. A total gas production of approximately 45,000,000 cubic feet per day from the two fields was obtained before the end of 1927, approximately 40,000,000 cubic feet of which went to Houston from the White Point field alone, through two pipe lines.

From 1928 to 1930 a few gas wells were drilled, including several from which gas was transported by the Moran Gas Company to the Humble oil refinery at Ingleside on Corpus Christi Bay and to villages near by. The Moran Gas Company later sold its holdings to the Houston Gulf Gas Company, which by this time had been merged by the Moody-Seagraves group with other properties into the United Gas Company.

In 1930, the Saxet Oil Company contracted with the fee holders at White Point to drill several deep tests for oil. The first of these locations was made by the writer on the White Point Oil and Gas Company fee, Rachal Ranch, the well being known as Rachal No. 17. This location is in the center of the developed gas area and is presumably high on structure as defined by the gas sands. Oil had previously been discovered in the South Texas Gulf Coast region at places within 30 miles of the coast at Kingsville, Refugio, and Saxet,[1] at distances of 35, 30, and 4 miles, respectively, and all approximately the same distance from the coast as White Point.

On November 11, 1930, Rachal No. 17 produced 25 barrels of "pipe-line oil" from sand between 4,878 and 4,892 feet. The well was deepened to 4,902 feet, and on December 2, 1930, produced 124 barrels of oil and 24,000,000 cubic feet of gas through a separator without showing water. Screen was set from 4,878 to 4,902 feet, the formation being sand with sandy shale. Closed pressure at the 4,892-foot depth was 1,200 pounds per square inch at the casing-head. At the 4,902-foot depth, while the well was blowing through the separator, pressure on the casing was 1,580 pounds and on the tubing 1,250 pounds.

The well was then connected with the gas pipe line, and the gas flow was choked to 4,000,000-6,000,000 cubic feet per day. The well then produced 50 barrels of oil.

A distillation test of the oil gave the following results.

[1]W. Armstrong Price, "Discovery of Oil in Saxet Gas Field, Nueces County, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 10 (October, 1930), p. 1351.

Oil	Gravity (Degrees Bé.)	Per Cent	Initial Boiling Point (Degrees F.)	End Point (Degrees F.)	Flash (Degrees F.)	Fire (Degrees F.)
Crude	31.5	100.0				
Naphtha	46.5	33.6	220	412		
Gas oil	31.1	30.0			190	210
Lubricating stock	19.5	36.0			310	340
Loss		0.4				

On December 12, the flow of oil and gas was stopped with mud, screen pulled, and the well deepened, but no lower oil-bearing sand was found. Gas sands were cored from 5,259 through 5,273 feet and from 5,769 through 5,776 feet, and the well was plugged back to the original oil and gas sand at 4,878-4,903, with 20 feet of screen. The total depth of this well was 6,000 feet.

Across Nueces Bay, on the south, in the Saxet field, production from the Saxet Oil Company's Dunn No. 6, the discovery well in the Saxet field, has declined from approximately 125 barrels to 25 barrels per day in 4 months, but the history of the well favors the assumption that the casing seat is leaking. The plug was drilled only 3 days after cement was set. First measurements of the oil in the pit indicated a daily rate of production of 300 barrels of oil without water. In a short time, the well went entirely to salt water, but was brought back to a production of 125 barrels of oil.

Before 1930, there were known in the White Point and Saxet fields and the immediately surrounding area, including a zone not more than a mile or two beyond the present gas area, approximately five horizons between 1,000 and 4,000 feet in depth, where oil had been indicated in the core. During 1930, seven or eight horizons where oil has been produced or shown in the core have been discovered in the two fields. Oil has been produced from two wells, and, as this paper is written, a test in a third (the second for the Saxet field) has shown a large amount of oil. This well is the Houston Oil Company's Hunter No. 1, where 212 feet of 24° Bé. oil flowed into the drill stem in 4 minutes. This is evidently the same sand as that of the Saxet Oil Company's Donigan No. 1, a gasser which showed oil with the gas. The location of the Hunter well is 1 mile west of the discovery well of the Saxet field.

The stratigraphic distribution of these oil showings seems to be as follows, although there is some doubt as to the position of the Miocene-Oligocene contact in the White Point field.

Age of Formations	Number of Oil-Bearing Horizons
Lissie-Reynosa, non-marine	2
Miocene, non-marine	8 Discovery sand in Saxet field in Miocene (?) Catahoula
Oligocene, marine	2 Discovery sand in White Point field may be at top of Frio Oligocene

Of the 98 wells drilled in, or immediately adjacent to, the two fields, 18 have had showings of oil. The deepest oil sand is at 4,900 feet, in the Rachal No. 17, which is near the base of the marine Middle Oligocene, or in the top of the Frio. Below this depth, in both fields, the sands contain salt water and have shown no oil. A core from a well east of the Saxet field, the Baldwin No. 1, showed oil at 5,216 feet. The absence, or seeming absence, of oil below the marine Middle Oligocene raises an interesting question as to whether this is a barren zone on favorable structure or whether the deeper strata have a structural position different from the upper strata. This problem involves a consideration of the mode of accumulation of oil, of source beds, and of possible faulting. These are problems which further drilling alone will solve.

To date, only a very few tests have been made of the twelve or thirteen horizons at which oil has been found. Neither producing well has been offset. The position of the two fields midway between a prolific field, Refugio, and a field where steady production has not been obtained, Kingsville, leaves the future of the fields undecided. But the large number of oil-bearing sands found, the evidences of favorable structure, the high gas pressures, and the scattered deep drilling encourage the belief that commercial production of oil will be developed. The gas reserves of the field have already been proved to be large in sands seemingly above the best oil showings.

The drilling has demonstrated that careful technical supervision is needed for the efficient production of oil at Refugio and that similar general conditions exist at White Point and Saxet. The sands are lenticular. Water sands closely overlie some oil sands at Refugio and the same condition has been recognized at Saxet. After a producing sand is found, careful coring is needed to determine the best positions for casing and screen. First-class cementing is necessary, and coring of cement plugs is desirable. Judging cores of sands for production is difficult because of the different gravities of the oils, with their different color, odor, and volatility. The presence of much dissolved calcium carbonate in many

sands necessitates prompt inspection and tests for lithologic character and porosity, because cores harden in the air. Subsurface studies are made more difficult by the absence of reliable key horizons above the *Discorbis* and *Heterostegina* foraminiferal zones of the Middle Oligocene. These are problems which necessitate close technical attention.

The high gas pressures indicate that enough strings of casing must be set to prevent migration and leakage of gas from one bed to another in order to protect the oil and gas reserves and to reduce blow-out hazards. The difficulty of judging cores for oil production indicates that screen must be set for adequate tests of most sands showing oil, being particularly necessary in the deeper sands where drill-stem testers fail to hold.

At Refugio, the small size of leases in the town-site resulted in many more wells being drilled than were necessary to develop the field economically. As a result, profits were correspondingly reduced. This situation will not occur at White Point and Saxet, for although the latter field is near the city of Corpus Christi, it is outside the area of small tracts bordering the town.

W. Armstrong Price

Consulting Geologist
Corpus Christi, Texas
December 31, 1930

MECHANICS AND GEOLOGY

The problem of deformation of the rocks of the earth's crust is undeniably a problem in mechanics of materials, and a knowledge of this is obviously essential in attacking the problems of structural geology. Unfortunately it is not feasible to include courses in mechanics in the ordinary training of a geologist and comparatively few geologists are trained in mechanics.

C. R. Van Hise made a thorough study of theoretical mechanics, applied this knowledge to problems of rock deformation, and has written a most excellent discussion of the mechanics of rock deformation. He studied particularly the origin of structures with respect to stresses of various types. His geological data were based on years of field observation and his interpretations are mechanically sound. His conclusions are published in his paper, "Principles of North American Pre-Cambrian Geology," in the 16th Annual Report of the U. S. Geological Survey.

The writer wishes to urge a wider appreciation and a more general application of this classic work of Van Hise.

LYNDON L. FOLEY

TULSA, OKLAHOMA
January 12, 1931

HEAVY DUTCHER OIL IN BRISTOW DISTRICT, OKLAHOMA

The gravity of most of the Dutcher oil produced in the Bristow district ranges from 29° to 34° Bé. On November 6, 1930, the Deep Rock Oil Corporation, the Reiter-Foster Oil Corporation, the Peerless Oil Producing Company, and E. L. Jillson found production in the Dutcher sand in this district which is exceptional because of its low gravity and high asphalt content. The location of this well, Rowley No. 1, is in the NW., SW., SE. 1/4 of Sec. 17, T. 16 N., R. 8 E. The top of the Dutcher sand was found at 3,300 feet. The tools were blown 35 feet off bottom and stuck when the sand was topped, and after the tools were recovered the column of oil stood at a depth of 2,200 feet. Very little gas accompanied the oil. A 24-hour swabbing test failed to lower the fluid level and the well was swabbed at the rate of approximately 80 barrels an hour. The well has not been deepened and is now shut in.

The following analysis of the oil was made by the Deep Rock Refining Company at Cushing.

Gravity	18.3° Bé.
Color	Black
Bottom sediment	0.2 per cent
Asphalt	92.0 per cent
Sulphur	0.908 per cent

A distillation test showed 6 per cent gasoline and 2 per cent kerosene.

Figure 1 shows the location of Dutcher sand production in the Bristow district. In part of T. 14 N., R. 8, 9, and 10 E., the Dutcher production may be from the Cromwell. In Sec. 30, T. 14 N., R. 8 E., Ira Cram, geologist for The Pure Oil Company, reports Wapanucka limestone above the producing sand, indicating that here, at least, production is from the Cromwell. Farther north the Wapanucka limestone and Cromwell sand are not present and, because of overlap, the Dutcher rests on Fayetteville shale or "Mississippi lime." It is interesting to note that the gravity of the so-called "Dutcher" oil in the two pools in T. 14 N., R. 8 E., ranges from 40° to 42° Bé.; whereas the average grav-

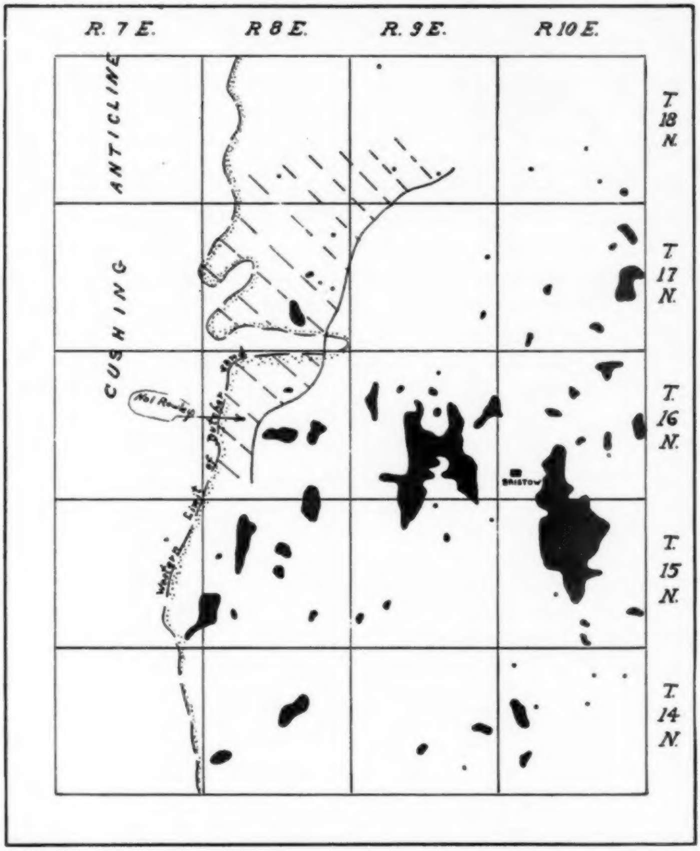


FIG. 1.—Map showing areas where the Dutcher sand is productive, and western limit of this sand. In several wells within the dashed area heavy black asphaltic oil has been found in the Dutcher. Black areas show past and present producing pools in the Dutcher sand. Scale: 1 township = approximately 6 miles.

ity of the Dutcher oil farther north is much lower, being approximately 32°.

Within the dashed area shown in Figure 1 in T. 16, 17, and 18 N., R. 8 E., and T. 18 N., R. 9 E., the oil found in the Dutcher sand has been of low gravity and high asphalt content. In Sec. 10, T. 16 N.,

R. 8 E., the gravity was 19 and the asphalt content approximately 40 per cent. In the pool in Sections 26 and 27, T. 17 N., R. 8 E., the gravity ranges from 24° to 28°. A heavy black oil has been reported in the Dutcher in several other wells drilled in this township.

A heavy asphaltic oil found in this area indicates conditions that permitted oxidation of the oil and the escape of the lighter constituents. Two possible explanations for the localization of the heavy oil in this area are suggested: (1) the action of underground waters on the oil, such ground waters being related to the old Cushing land area at the west; (2) a break in deposition permitting erosion of the Dutcher sand which may have extended west farther than well data now indicate. Part of the Cushing ridge remained a land area until Bartlesville time because, on the Dropright dome in the northwest part of T. 18 N., R. 7 E., Bartlesville sand rests on Arbuckle and other Ordovician rocks.[1] It is known that ground waters have a marked effect on gravity of oil. This is especially true where the sulphate content is being renewed by waters circulating from the outcrop.[2]

Charles G. Carlson

Peerless Oil Producing Company
Tulsa, Oklahoma
January 14, 1931

[1]T. E. Weirich, "Cushing Oil and Gas Field," *Structure of Typical American Oil Fields*, Vol. II (Amer. Assoc. Petrol. Geol., 1929), pp. 396-406.

[2]Edward L. Estabrook, "Analyses of Wyoming Oil-Field Waters," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 2 (February, 1925), pp. 235-46.

REVIEWS AND NEW PUBLICATIONS

"Paleozoic Rocks." By WILLIAM CLIFFORD MORSE. *Mississippi State Geol. Survey Bull. 23* (University, 1930). 212 pp., 15 figs., 23 pls.

"Paleozoic Rocks" is the first adequate stratigraphic, paleontologic, and economic report of these very interesting beds of Tishomingo County, the northeastern county of Mississippi, and of the adjacent parts of Alabama and Tennessee. The report is of especial value to geologists and others interested in petroleum and natural gas production, because for the first time the bitumen-bearing beds, some of which, no doubt, yield the natural gas of the new Amory gas field, are named, described, and referred to their proper stratigraphic position. The volume is dedicated to the author's son, Paul Franklin Morse (1897-1929).

RECENT PUBLICATIONS

CALIFORNIA

"Geophysical Notes on California Area," by Paul B. Whitney. *Oil and Gas Journal* (Tulsa, Oklahoma, December 25, 1930), pp. 32, 146, 149, 150, 153, 10 figs.

"Buttonwillow Gas Field," by E. H. Musser. *California Oil Fields*, Vol. 15, No. 3 (January, February, March, 1930), pp. 5-20, 4 pls. Issued by Department of Natural Resources, Division of Oil and Gas, Ferry Building, San Francisco, California.

"Oil Possibilities of Terra Bella," by Lew Suverkrop. *Oil Bulletin* (Los Angeles, California, January, 1931), pp. 14-17, 76, 5 illus.

CZECHO-SLOVAKIA

"Die mährische Flyschzone und die miozäne Vortiefe mit Rücksicht auf die Ölführung," by K. Zapletal. *Petrol. Zeits.* (Berlin, December 3, 1930), pp. 1180-89, 1 illus.

GENERAL

"The Geology of Some Salt Plugs in Laristan (Southern Persia)," by John Vernon Harrison. *Quar. Jour. Geol. Soc.*, Vol. 86, Pt. 4, No. 344 (London, England, December, 1930), pp. 463-522, 19 figs., 7 pls. Bibliography.

Erdöl und Verwandte Stoffe, by Rudolf Koetschau. (Theodor Steinkopff, Dresden and Leipzig, Germany, 1930.) 150 pp., 32 illus. Price, RM. 8.

"Zur experimentallen Tektonik." V. "Vergleichende Analyse dreier Verschiebungen," by Hans Cloos. *Geologische Rundschau*, Vol. 21, No. 6 (Berlin, 1930), pp. 353-67, 14 illus.

Oil. (American Petroleum Institute, 250 Park Avenue, New York, New York.) 5 × 6¾ inches. 192 pp. Paper. Price varies with number of copies

ordered; single copy, $0.50. *Oil* is a series of 12 booklets on the oil industry, now published as one book; text and illustrations are the same as in separate booklets, which may still be ordered in pamphlet form.

A General Index to the Journal of Geology, Volumes I to XXXV—1893-1927. Editor, Rollin T. Chamberlin; compiled by Dorothy S. Neff. (The University of Chicago Press, Chicago, Illinois, 1930.) A single, convenient, comprehensive index containing more itemized detail than a mere combination of the thirty-five annual indexes. 279 pp. Price, $5.10.

"Geothermal Phenomena and Geological History with Special Reference to Old Structures in Geothermal Equilibrium," by M. W. Strong. *Jour. Inst. Petrol. Tech.*, Vol. 16, No. 86 (London, England, December, 1930), pp. 889-901, 12 figs.

GEOPHYSICS

"Isostasy: A Critical Review," by M. King Hubbert and F. A. Melton. *Jour. Geol.*, Vol. 37, No. 8 (Chicago, Illinois, November-December, 1930), pp. 673-95, 5 figs.

INDIA

"Quinquennial Review of the Mineral Production of India for the Years 1924 to 1928," by the Director and Senior Officers of the Geological Survey of India. *Records of the Geological Survey of India*, Vol. 44 (Calcutta, October, 1930). Pages 257-73 are devoted to "Petroleum," by E. H. Pascoe, director.

MEXICO

"Eine neue Erdölzone in Mexiko?" by K. G. Müllerried. *Petrol. Zeits.* (Berlin, December 3, 1930), pp. 1196-98, 1 illus.

NEW MEXICO

"Hobbs Area Presents Many Geological Problems," by Floyd Swindell, *Oil Weekly* (Houston, Texas, January 2, 1931), pp. 25-26, 90. 1 illus., map.

NORTH AMERICA

"Occurrence of Petroleum in North America," by Sidney Powers. *Amer. Inst. Min. Met. Eng. Tech. Pub. 377* (New York, N. Y., January, 1931). 46 pp., 15 figs. Bibliography.

POLAND

"Compte Rendu du Ier Congrès de la Géologie du Pétrole, à Lwów, 14-15 XII. 1929," published by Service Géologique de Pologne, Station Géologique Karpatique, Lwów, Poland (1930). Contains: "Quelques résultats des recherches géologiques dans les Karpates et dans l'avant-pays et programme des travaux pour l'avenir immédiat," by K. Tolwinski; "Les homologies podoliens-karpatiques, leur application aux recherches géophysiques dans la zone subkarpatique," by W. Teisseyre; "Les problèmes de la pétrographie des roches sédimentaires en liaison avec les recherches géologiques dans les Karpates," by J. Tokarski; "Stratigraphie du Tertiaire karpatique à la base de la faune des poissons," by B. Böhm; "De l'application des methodes géophysiques aux recherches de la géologie du pétrole dans les Karpates et l'avant-pays," by E. W. Janczewski; "Sur le levé magnetique des Karpates de Skole et de leur

avant-pays," by E. Stenz and H. Orkisz; "De la géologie de la région d'Ustrzyki Dolne," by L. Horwitz; "Conditions générales d'application de la science géologique et technique dans l'industrie pétrolière des États Unis d'Amérique du Nord," by K. Bohdanowicz; "Organisation de la géologie du pétrole en Pologne," by St. Weigner.

UTAH

"The Geology and Commercial Possibilities of a Large Deposit of Bituminous Sandstone in Asphalt Ridge, a Few Miles Southwest of Vernal in Uintah County, Utah," by E. M. Spieker. *U. S. Geol. Survey Bull. 822-C* (Washington, D. C., 1930).

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

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Arnaldo Belluigi, Rome, Italy
W. P. Haynes, B. B. Weatherby, Andrew Gilmour
Charles Bohdanowicz, Warsaw, Poland
W. P. Haynes, John L. Ferguson, Dollie Radler
Frederic A. Bush, Tulsa, Okla.
Bruce H. Harlton, Lyndon L. Foley, Dollie Radler
C. D. Johnson, Denver, Colo.
Ross L. Heaton, A. E. Brainerd, Charles S. Lavington
Thomas S. Lovering, Golden, Colo.
David White, M. R. Campbell, Hugh D. Miser
Conrad Schlumberger, Paris, France
W. P. Haynes, B. B. Weatherby, Andrew Gilmour
Dart Wantland, Golden, Colo.
C. A. Heiland, J. Harlan Johnson, W. A. Waldschmidt
William Edward Winn, Dallas, Tex.
Francis E. Heath, P. W. McFarland, James A. Waters

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Frank A. Moss, E. L. Ickes, Frederick P. Vickery
Pierre Bayle, Maracaibo, Venezuela, S. A.
C. A. Baird, H. E. Van Aubel, E. A. Ritter
James M. Boyles, Houston, Tex.
F. B. Plummer, W. L. Goldston, Jr., George D. Stevens
Thomas C. Craig, Amarillo, Tex.
Henry Rogatz, D. J. Wolff, H. E. Crum
Jarvis Garst, Monterrey, N. L., Mexico
J. L. Tatum, D. R. Semmes, R. J. Riggs
Ira M. Hicks, San Antonio, Tex.
Louis C. Roberts, Jr., W. W. Harvey, J. F. Hosterman
Louie C. Kirby, Beeville, Tex.
Frank C. Adams, John C. Miller, Bruce Whitcomb

J. Brookes Knight, New Haven, Conn.
H. R. Van Gilder, Alan Bateman, Raymond C. Moore
Walter W. Leach, Houston, Tex.
Howard E. Nessly, A. W. Weeks, Charles H. Row
Ernest O. Schillhahn, Pittsburgh, Pa.
Leon J. Pepperberg, Edmund M. Spieker, Edward V. O'Rourke
Edwin A. Taegel, Monterrey, N. L., Mexico
D. R. Semmes, R. J. Riggs, J. L. Tatum
Murray J. Wells, Chickasha, Okla.
C. E. Decker, Clyde M. Becker, Harry H. Nowlan
Percy O. Woods, Mt. Belvieu, Tex.
P. C. Murphy, F. Julius Fohs, Sidney A. Judson

FOR TRANSFER TO ACTIVE MEMBERSHIP

Richard W. Camp, Oklahoma City, Okla.
Clyde M. Becker, A. J. Williams, Paul Ruedemann
Lawrence W. Clark, San Antonio, Tex.
A. R. Denison, Dollie Radler, John L. Ferguson
Karl F. Hasselmann, Berlin, Germany
O. Stutzer, Chester Naramore, Leonard W. Orynski
C. Bjarne Rossebo, Oklahoma City, Okla.
Hubert E. Bale, R. D. Jones, A. H. Richards
George A. Severson, Maracaibo, Venezuela, S. A.
Chester Cassel, Roy E. Dickerson, V. E. Monnett

SAN ANTONIO MEETING, MARCH 19-21, 1931

Previous notices about the sixteenth annual meeting and instructions for preparation of manuscripts for the technical program have been published in the *Bulletin* of November and December, 1930 (pages 1485-86 and 1582-84), and January, 1931 (pages 99-100). Members are also referred to the regional editors, district representatives, and Association headquarters for further information and printed forms for titles and abstracts of manuscripts. A circular letter is also being prepared for mailing to every member, giving detailed information about reduced railroad fares, hotel accommodations and rates, field trips, and entertainment.

Manuscripts.—Abstracts should be sent to F. H. Lahee, Box 2880, Dallas, Texas, by February 20, in order to be included in the printed program. As no preprints of papers will be made for the meeting this year, authors are invited to submit three carbon copies of their manuscripts with the first copy in order to facilitate discussion in advance of the meeting. Manuscripts thus submitted in advance should be in Dr. Lahee's hands by February 15. Papers included in the Association program are considered Association property and are not to be printed elsewhere than in Association publications, except by specific arrangement with the business manager under the supervision of the executive committee.

Railroad rates.—The railroads have granted reduced rates as usual. Identification certificates are being sent each member. The round-trip ticket will

be sold on the basis of one and one-half of current one-way fare with a return limit of approximately one week after the meeting; other specifications, as dates of sale, longer return limits, and diverse return routes, are shown in the instructions sent out with the identification certificates. Only members and dependent members of their families are entitled to reduced rates. THE IDENTIFICATION CERTIFICATE MUST BE PRESENTED TO TICKET AGENT BEFORE THE TICKET IS PURCHASED. THE ROUND-TRIP TICKET MUST BE PURCHASED AT BEGINNING OF TRIP; RETURN PARTS OF TICKETS MUST BE VALIDATED AT REGULAR TICKET OFFICE OF RETURN ROUTE AT SAN ANTONIO.

General information.—The technical program is in charge of F. H. Lahee, Box 2880, Dallas, Texas. The general chairman of the local committee is D. R. Semmes, 1601 Milam Building, San Antonio, who is also president of the local section of the Association. The Gunter Hotel is convention headquarters. The registration fee for each person attending the convention is $3.00. There will be sessions for general geology, geophysics, and paleontology.

Papers.—In addition to the twenty-three papers listed in the January *Bulletin* (pages 99-100), the following titles have been received.

Texas

"Chapman Field of Williamson County, Texas," by E. H. Sellards

"Pre-Carboniferous Stratigraphy of Marathon Uplift," by Philip B. King

"Structural Development of South Permian Basin Area of West Texas, with Particular Regard to Its Effect on Stratigraphy," by R. L. Cannon

"Glacial Deposits of the Earlier Anthracolitic in Haymond Formation of the Marathon Area," by Charles Laurence Baker

Geophysics

"Some Results of Magnetometer Surveys in California," by E. D. Lynton

Origin

"Bacterial Genesis of Hydrocarbons from Fatty Acids," by Lewis A. Thayer

"Evidence Concerning Rôle of Bacteria in Formation of Natural Hydro-Carbons," by Harold E. Hammer and S. A. Waksman

"Characters of Oil and Origin of Differences of Oil in Various Environments," by Paul Weaver

"Review of Current Ideas as to Source Beds for Petroleum," by L. C. Snider

Compaction, Migration, Accumulation

"Vertical *versus* Lateral Migration of Oil," by F. H. Lahee

"Present Interpretations of the Structural Theory for Oil and Gas Migration and Accumulation," by Chester W. Washburne

"Importance of Compaction and Its Effect upon Petroleum Accumulation," by L. F. Athy

"Physical and Chemical Factors in Accumulation and Discharge of Oil," by P. G. Nutting

"Present Interpretations of the Structural Theory for Oil and Gas Migration and Accumulation," by (1) John L. Rich (2) W. Ross Keyte

"Important Phenomena Concerning Oil and Gas Accumulation in Limestone," by W. V. Howard

"Relation of Porosity and Cementation to Production of Oil and Gas," by A. F. Melcher, P. G. Nutting, and Charles R. Fettke

Oil-Field Waters

"Subsurface Waters in Maracaibo Lake Basin, Venezuela," by E. A. Ritter and J. A. Smith

"Importance of Bio-Chemical Study of Oil-Field Waters," by Roy L. Ginter

Oil in Igneous Rocks

"Oil Production from Granite, Gray County, Texas," by Max Bauer

Miscellaneous

"Richland Gas-Producing District, Louisiana," by Dugald Gordon

"Variations of Gravity of Oil in Pools of Mid-Continent Region," by Charles H. Pishny

Stratigraphy of Permian Beds in Northwestern Oklahoma," by Noel Evans

"Hobbs Oil Field, New Mexico," by Ronald K. DeFord

"Interpretation of Local Structural Development in Areas Associated with Deposits of Petroleum,"

(1) "Mid-Continent," by Alex. W. McCoy,

(2) "Salt Domes," by Marcus A. Hanna

"Oil Occurrences in Pre-Cambrian," by Theodore A. Link

Events.—A tentative outline of events is as follows.

Tuesday, March 17

Preliminary registration and committee meetings, Gunter Hotel

Wednesday, March 18

Registration, Gunter Hotel

Field trips northeast of San Antonio: Darst Creek-Luling Balcones fault line

Meetings of executive, research, and general business committees

Thursday, March 19

Registration, Gunter Hotel

Convention opens. Technical sessions, Municipal Auditorium

Appointment of committees (resolutions, ballot, etc.)

Nomination of officers

8:15 P. M., Lecture, Laurence M. Gould, Byrd Antarctic Expedition, Municipal Auditorium

Friday, March 20

Ballot boxes open all day. Technical sessions, Gunter Hotel

Golf tournament. Special and Bostick trophies, San Antonio Country Club

Entertainment and dance, Municipal Auditorium

Saturday, March 21

Sixteenth annual business meeting, Gunter Hotel

Announcement of new officers

Technical sessions

Trips to Laredo and Mexico and Marathon area

Sunday, March 22

Trip northwest of San Antonio: Edwards Plateau

Exhibits.—An exhibit of geological equipment will occupy the Mezzanine Lounge. Space for members' exhibits of maps and charts not included in the technical program will also be provided.

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

Sidney Powers, *chairman*, Box 2022, Tulsa, Oklahoma
Marvin Lee, *secretary*, 612-18 Brown Building, Wichita, Kansas
J. Y. Snyder, 1211 City Bank Building, Shreveport, Louisiana
R. D. Reed, 1110 Glendon Way, South Pasadena, California
F. H. Lahee, Box 2880, Dallas, Texas

GENERAL BUSINESS COMMITTEE

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Alexander Deussen (1931), *vice-chairman*, 1606 Post Dispatch Building, Houston, Texas

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S. P. Borden (1931)	Frederic H. Lahee (1931)	R. D. Reed (1931)
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Victor Cotner (1932)	Theodore A. Link (1931)	J. Y. Snyder (1931)
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A. W. Duston (1931)	H. D. Miser (1932)	A. C. Trowbridge (1931)
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Donald C. Barton (1933), *vice-chairman*, Petroleum Building, Houston, Texas

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F. H. Lahee (1931)	A. I. Levorsen (1932)	W. T. Thom, Jr. (1932)
R. C. Moore (1931)	Sidney Powers (1932)	F. M. Van Tuyl (1932)
F. B. Plummer (1931)	R. D. Reed (1932)	W. E. Wrather (1932)
M. K. Read (1931)	L. C. Snider (1932)	

REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

Alex W. McCoy (1931) — R. C. Moore (1933)

REPRESENTATIVES ON NATIONAL STRATIGRAPHIC NOMENCLATURE COMMITTEE

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M. G. Cheney — C. J. Hares

METHOD OF ELECTION OF OFFICERS

W. E. Wrather, *chairman*, 4300 Overhill Drive, Dallas, Texas
H. B. Fuqua, *vice-chairman*, Box 737, Fort Worth, Texas

A. F. Crider	W. B. Heroy	Frank S. Hudson
R. E. Dickerson	J. V. Howell	

REVOLVING PUBLICATION FUND

E. DeGolyer, *chairman*, 65 Broadway, New York, N. Y.

RESEARCH FUND

Luther H. White, *chairman*, J. A. Hull Oil Company, Tulsa, Okla.

ASSOCIATION SEAL COMMITTEE

R. C. Moore, *chairman*, University of Kansas, Lawrence, Kansas
Joseph M. Wilson — C. A. Cheney — Harold W. Hoots

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

Employment

The Association maintains an employment service at headquarters under the supervision of the business manager.

This service is available to members who desire new positions and to companies and others who desire Association members as employees. All requests and information are handled confidentially and gratuitously.

To make this service of maximum value it is essential that members coöperate fully with headquarters especially concerning positions available to active and associate members.

James Perrin Smith, professor of paleontology (emeritus) at Stanford University, California, died on January 1, 1931, at the age of 66 years.

Sam Zimerman, formerly of the Humble Oil and Refining Company, Houston, Texas, is employed by the Nederlandsche Koloniale Petroleum Maatschappij, and is doing seismograph work in Sumatra. His headquarters' address is in care of the N. K. P. M., Batavia, Java, D. E. I.

W. A. Baker, of the geological department of the Transcontinental Petroleum Company, has been transferred from Tampico to Monterrey, Mexico, where his address is in care of the geological department, Cia. de Petr. Mercedes, S. A., Apartado 269.

C. E. Shoenfelt is vice-president of Petroleum Information, Inc., 401 Continental Oil Building, Denver, Colorado.

V. R. Garfias, manager, foreign oil department, Henry L. Doherty and Company, New York City, has an article in the January 2 issue of the *Oil Weekly*, entitled "World Output Will Show Small Decline in 1931."

Frank R. Clark, of the Mid-Kansas Oil and Gas Company, Tulsa, addressed the Tulsa Geological Society, January 5, 1931, on the subject of "Oil Pools."

W. Tappolet has changed his address from Tampico to C. M. P. "El Aguila," S. A., Apartado 86, Puerto Mexico, Ver., Mexico.

Donald C. Barton, consulting geologist and geophysicist, of Houston, Texas, addressed the Houston Geological Society, December 16, 1930, on "Aeroplane Photograph of Blue Ridge and Vicinity."

J. S. Ross, engineer of the Southern States Company, Inc., has moved from Shreveport, Louisiana, to 1409 South Quincy Street, Tulsa, Oklahoma.

Mr. Ross has an article in the December 25 issue of the *Oil and Gas Journal*, entitled "Deep Wells Are Tubed Successfully."

CARL BEAL, A. H. HELLER, and GRANT CORBY, consulting geologists, Los Angeles, California, have dissolved their partnership. The firm will continue under the name of Beal and Corby.

The officers of the Kansas Stratigraphical Society, recently organized at Wichita, are: president, MOSES KORNFELD, of the Atlantic Oil Producing Company; vice-president, E. H. CAHILL, of the Skelly Oil Company; secretary, LOREN CRUM, of Lee and Garlough; treasurer, BETTY KELLETT, of the Amerada Petroleum Corporation; and recording secretary, ARTHUR W. PRICE, of the Gypsy Oil Company. The society will meet on the first and third Monday of each month, at the offices of the various companies. The programs will consist chiefly of projects pertaining to stratigraphy or paleontology.

F. S. HUDSON, of the Shell Company, at Los Angeles, California, plans to leave, February 1, for Europe, where he will be engaged in research for a year.

R. N. NELSON, geologist for the Standard Oil Company in the Los Angeles basin, accompanied by Mrs. Nelson, has gone to Java, to carry on geological work there.

The Branner Club, Los Angeles, California, has elected the following officers for 1931: president, HAROLD HOOTS, Union Oil Company of California; secretary-treasurer, W. D. RANKIN, Continental Oil Company. The Branner Club, named after the late JOHN CASPER BRANNER, formerly head of the department of geology at Stanford University and subsequently president of that institution, is composed of approximately 100 members, geologists of Southern California. Meetings are held monthly and visiting geologists are invited to attend.

W. C. MORSE is spending a year's leave of absence from Mississippi Agricultural and Mechanical College as visiting professor of geology at the University of North Carolina, Chapel Hill.

The Kansas Geological Society will hold a fifth annual field conference during September, 1931, in the Wichita, Arbuckle, and Ouachita Mountains of southern Oklahoma. The members of the committee in charge of arrangements are N. W. BASS, chairman, E. A. WYMAN, and J. L. GARLOUGH.

JOHN R. REEVES, of the Empire Gas and Fuel Company, is in charge of their exploration in Pennsylvania and New York.

W. T. FORAN, geologist for the Carter Oil Company, Tulsa, Oklahoma, is working in Kansas.

A. O. HAYES, Rutgers University, New Brunswick, New Jersey, has an article in the January, 1931, issue of *Mining and Metallurgy*, entitled "Mining Geology in 1930."

WILLIAM A. P. GRAHAM, of the department of geology, Ohio State University, Columbus, Ohio, has an article in the November-December, 1930,

issue of the *Journal of Geology*, entitled "A Textural and Petrographic Study of the Cambrian Sandstones of Minnesota."

A stranger with a plausible hard-luck story has been misrepresenting himself to geologists in the Mid-Continent region. Claiming close friendship or relationship with well-known Association members, he solicits loans of three or four dollars from other members.

JAMES B. TEMPLETON, who was working in Europe in August, returned on December 20, and is at present located in Muskogee, Oklahoma, where his address is 2910 West Broadway.

JOSEPH A. CUSHMAN, director of the Cushman Laboratory for Foraminiferal Research, Sharon, Massachusetts, and JULIAN D. BARKSDALE, Stanford University, California, are the authors of "Eocene Foraminifera from Martinez, California," issued as Volume 1, Number 2, of *Contributions from the Department of Geology of Stanford University*.

The Rocky Mountain Association of Petroleum Geologists, in their meeting on December 18, 1930, elected the following officers for the ensuing year: president, J. HARLAN JOHNSON, Colorado School of Mines, Golden, Colorado; vice-president, C. E. DOBBIN, U. S. Geological Survey, 212 Custom House Building, Denver, Colorado; vice-president, ROSS L. HEATON, consulting geologist, 2374 Elm Street, Denver, Colorado; and secretary-treasurer, W. A. WALDSCHMIDT, Colorado School of Mines, Golden, Colorado.

JAMES O. LEWIS, petroleum engineer, 415 Central National Bank Building, Tulsa, Oklahoma, has an article in the January 8 issue of the *Oil and Gas Journal* entitled "Lifting Cost in Stripper Area Is Small."

Officers of the recently organized Midland Geological Club are: president, GEORGES VORBE, of the Texas Pacific Coal and Oil Company, at Midland, Texas; vice-president, W. T. HOEY; and secretary-treasurer, W. W. IRWIN. A luncheon and meeting will be held each month at the Scharbauer Hotel. Twenty-four charter members compose the club.

E. K. PARKS, petroleum engineer, Bin XX, Taft, California, has a brief article in the January, 1931, issue of the *Oil Bulletin* on "Factors of Underground Flow of Fluids," in reply to BYRON B. BOATRIGHT's discussion of "Flow of Oil Through Reservoir Rocks," published in the December issue of that magazine.

B. W. GILLESPIE, formerly superintendent of California service for the Elliott Core Drilling Company, Los Angeles, California, became sales manager of that company, effective January 1, 1931.

F. G. CLAPP, 50 Church Street, New York, New York, gave a travelogue on Persia before the January 9 meeting of the Dallas Petroleum Geologists. His discussion was illustrated by motion pictures on methods of oil field operation, exploration difficulties, and interesting native customs.

G. E. ANDERSON, of the department of geology, University of Oklahoma, Norman, Oklahoma, addressed the Tulsa Geological Society on January 19, 1931, on the subject of "Sedimentation."

CHARLES LAURENCE BAKER, 525 Commercial Bank Building, Houston, Texas, addressed the San Antonio Section of the Association, November 3, 1930, on the stratigraphy and structure of the Marathon region of southwest Texas. On December 1, F. G. CLAPP, of New York City, gave an illustrated lecture on Persia. Mr. Clapp addressed the section again on December 22, talking on the oil fields of Persia and Iraq, and discussing technical matters in more detail than in his previous lecture. On December 15, DJEVAD EYOUB, 302 Furr Drive, San Antonio, Texas, addressed the section on the geology and oil prospects of Turkey. At the monthly meeting held on January 5, 1931, OLIN G. BELL, Box 548, Laredo, Texas, conducted a symposium on the Laredo district of south Texas and the adjacent parts of Mexico.

H. E. MUNSON has returned to the Mid-Continent after spending 6 months in Alberta, Canada. His address is in care of Dr. D. O. Munson, Pittsburg, Kansas.

CHARLES LAURENCE BAKER, E. H. SELLARDS, and PHILIP B. KING announce the discovery of possible evidence of Paleozoic glaciation in the Haymond formation of the Marathon area in West Texas. For those interested in seeing these evidences, a trip will probably be led by Mr. Baker to the type localities immediately following the San Antonio convention.

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